Issues around fisheries for small pelagic fish
Fox, Clive

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Issues around fisheries for small pelagic fish

Clive J Fox
Citation

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Executive summary

This review examines the role of “small pelagic fish” (SPF), and their fisheries, in marine ecosystems. The term “small pelagic fish” is a loose definition usually taken to include small to intermediate-sized species which live mainly in the water column. An alternate term sometimes used is “forage fish”, generally taken to include those species which feed largely on zooplankton and phytoplankton and thus form important trophic links in many marine foodwebs. However other workers have questioned the use of this term since most small fish are preyed upon by other (often larger) members of marine foodwebs.

Many of the SPF species form large schools and this makes them attractive targets for fisheries. SPF thus find a wide range of uses for humans including direct consumption (as fresh or preserved fish) and as raw materials for processing into fish meals and oils (Alder and Pauly 2006). A significant proportion is also used in production of pet foods and a smaller fraction of raw oil around 200 Kt is processed into health supplements (Shepherd and Jackson 2013). The demand for both fresh, preserved and reduction products derived from SPF is growing as human population increases and affluent societies increasingly focus on “healthy” diets. There are also trends for increased demand for perceived “high-status” foods, such as Atlantic salmon (the majority of which is farmed) and tuna from countries such as China. Whilst some farmed fish species do not have a requirement for marine fish oils in the diet, species such as Atlantic salmon do. Tuna fattening has also emerged as a relatively recent aquaculture activity which is generating increasing demands for small-fish to use as fresh feed. Trends in consumer buying power are likely to continue to fuel increasing demand for these products but, unless alternative feed sources can be found, continued growth of these sectors may be unsustainable. As in other areas of fisheries management, the key challenge will be managing SPF fisheries in a manner that meets as much human demand as possible, whilst not depleting the stocks themselves or impacting other components of the marine foodwebs which rely on these species as prey.

Many SPF species mature relatively young and have high potential rates of population increase so that, based on their life-history characteristics, they can be classified as generally having low vulnerability (Tables 1-3). However, this does not mean that their populations cannot be seriously depleted by over-fishing when other environmental, ecological, behavioural and socio-economic factors are taken into account. Whether SPF stocks are more or less susceptible to collapses compared with other longer-lived species has been debated. Mullon et al. (2005) suggested they were slightly less likely (23% of herring and anchovy had collapsed at some point compared with 31% for demersals and 33% for salmon-trouts). Pinsky et al. (2011) reached a slightly different conclusion using a different analysis approach and found that SPF stocks were statistically as likely to have suffered collapses as stocks of larger and longer-lived species. The life history characteristics of SPF certainly mean that their populations often respond quickly to environmental fluctuations leading to rapid changes in abundance. If this is combined with a failure to match fishing capacity to production and to control fishing pressure rapidly enough when the productivity of the stocks...
declines, stock collapse is likely to occur. Well-known examples include Peruvian anchoveta, Californian sardine and North Sea herring stocks. On the positive side, the life history characteristics of SPF mean that they can often recover relatively rapidly from over-exploitation as long as environmental conditions also improve, a conclusion which appears to be borne out by experience with several stocks e.g. North Sea herring.

The recruitment (numbers of young fish surviving to enter the fishery) dynamics of SPF have long fascinated scientists leading to several classic recruitment control theories such as the “stable-ocean” and “window-of-opportunity” hypotheses. However, the range of potential factors affecting egg and larval survival combined with the temporal and spatial complexity of the ecosystems involved has meant that a full understanding of the mechanisms controlling “year-class strength” has remained elusive. Despite considerable effort in developing both statistical recruitment-environment models and coupled biological-oceanographic models, forecast skill remains rather limited and the forecast time-horizon tends to be too short to be of great assistance in medium to long-term fisheries planning. Given that we cannot forecast SPF recruitment with sufficient skill, assessment tools capable of tracking rapid shifts in stock productivity are required. Techniques such as larval abundance and acoustics surveys are therefore often employed but management processes need to be responsive to changes in productivity at appropriate timescales. The main lesson from the major global SPF collapses is that excess fishing and processing capacity should not be allowed to develop because it inevitably proves extremely difficult to cut back.

The increasing worldwide emphasis on “ecosystem-based approaches to fisheries management” also implies that trophic interactions of SPF need to be taken into account. The overall goal of EAFM is to ensure that fisheries do not compromise the wider biodiversity and functioning of marine ecosystems. Many SPF are important prey for other fish, birds and marine mammals and in some cases changes in SPF abundance have been shown to directly impact breeding success e.g. in penguins and black-legged kittiwake. SPF also provide vital nutrition for other fish which are themselves of commercial value e.g. many gadoids, Atlantic and Pacific salmon. Recent analyses have compared the economic value of direct catches of SPF against their economic value as prey for other fish which are commercially harvested. These results suggest that the potential value of SPF as prey should be taken into account when designing harvest strategies. Successful EAFM would also therefore help ensure long-term fisheries sustainability across a broader range of species. Many authors have considered that EAFM requires a shift away from traditional single-species management, at least as it has been commonly practiced in North America and Europe. However, implementing multi-species assessments remains a challenge because marine foodwebs are rarely fully characterised and models such as ECOPATH and ECOSIM have relatively high data demands. In some cases, where the fisheries are focussed largely on a restricted number of forage species, implementation of EAFM may be easier. Operational examples include the Baltic, Peruvian up-welling and Benguela. Even in these situations running multi-species models annually is challenging resulting in the development of ad hoc rules e.g. one-third for the birds. In many sub-tropical and tropical ecosystems, such detailed data are not available
(the main “forage” species caught are often not reported to species level because of difficulties in taxonomy and lack of local expertise and resources).

Analysis of the current status of SPF stocks globally shows widely varying results – some stocks are in a healthy state and are being sustainably fished whilst others are depleted. A lack of data on stock status is particularly apparent for areas such as the Mediterranean and Indian Ocean. Management plans have been developed and are operational for the major SPF stocks such as Peruvian anchoveta, South African and North Atlantic herring but plans are lacking for many of the smaller SPF fisheries. Access rights and ownership remains a particular problem for many of the smaller fisheries, a factor which can have negative consequences for sustainable local harvesting and lead to cash-poor fishers being deprived of a significant source of nutrition and income. Significant improvements are therefore required in the management of many SPF stocks if yields are to be maximised whilst protecting other SPF related ecosystem components.
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1. Species/Groups considered

The definition of “small pelagic fish” is somewhat vague leading to different species/groups being included by various authors (Ben-Tuvia 1995, Skjoldal 2011). In the fisheries literature the term is often reserved for those species which are fished by humans, although strictly it could refer to all small pelagic species.

The size limit for what defines “small” is similarly arbitrary (Fréon et al. 2005). Many authors would include herrings, sardines and anchovies but other, larger pelagic fish such as mackerels have also been included (Skjoldal 2011). Similarly, many species often included as SPF have sometimes been grouped as “middle-sized pelagics” (Ben-Tuvia 1995). The SeaAroundUs project defines the functional group “small pelagics” as having maximum sizes of < 30 cm but this definition excludes important commercial medium-sized pelagic species such as herring (*Clupea harengus*), which many authorities would certainly include. I have therefore chosen to exclude species with $L_{\text{max}} > 50$ cm so that species, such as herring, are included in this review. Any size boundary will of course give rise to arbitrary inclusion/exclusion – thus within the Carangidae, my definition includes some of the *Trachurus* spp. but excludes the commercially important European horse mackerel (*T. trachurus*). Most fish within a population will be considerably smaller than the maximum reported length but maximum length is a strong predictor for many other life history parameters so it does provide a convenient basis for separating smaller from larger pelagic species (Fréon et al. 2005).

The term “pelagic” means living near the surface or in the water column. This clearly separates “pelagics” from fish which live buried in the sediment e.g. European plaice (*Pleuronectes platessa*). However, even such species as these do venture into the water column at times e.g. during migration (Hunter et al. 2003). Classification of a species as “pelagic” is further complicated as many fish move between being closely associated with the seabed and being found in the water column for longer periods of time. This lifestyle is sometimes termed “benthic-pelagic”. Sandeels (Ammodytidae) for example move into the water column to feed or spawn but otherwise are generally buried in the sediment. Greater sand smelt (*Argentina silus*) also fall into this category and are commercially fished. The term “pelagic” can be further sub-divided, as in epi-pelagic, meso-pelagic, bathy-pelagic, abyssal-pelagic and hadal-pelagic, referring to increasing depth-zones of the water column. Other extensions include “nerito-pelagic” meaning inhabiting shallow coastal waters over the continental shelf. Whilst many species normally thought of as “pelagics” are found in the epi-pelagic zone (0-200 m depth), the deeper waters also support small pelagic species such as the hatchetfishes (Sternoptcheyidae). Depth classification is complicated by the fact that some species perform extensive vertical migrations, for example the meso-pelagic (200-1000 m) lanternfishes (Myctophidae) often move into the epi-pelagic to feed. The potential for significant meso-pelagic fisheries was recognised by (Suda 1973) although few of these species have been exploited since then (Olsen et al. 2011). If such fisheries did develop they could have significant impacts on marine foodwebs because many epi-pelagic fish are important prey for larger commercial species such as tunas and salmon (Scott and Scott 1988). Some authors also include groups such as the tropical fusiliers (Caesionidae) as
“pelagics” since they are found in the open waters around oceanic islands and coral reefs. I have generally chosen to exclude most species noted as “reef associated” unless their pelagic habit is specifically mentioned. It can thus be difficult to decide whether a species is really “pelagic” and judgement was used as to which species to include.

The term “small pelagics” is also sometimes used interchangeably with the term “forage fish” which is generally taken to mean small pelagic species which are preyed on by larger predators. Forage fish feed primarily on phyto- and zooplankton and facilitate the transfer of energy to higher trophic levels. They therefore form critical links in many marine foodwebs. To capture this aspect I have chosen to include species with reported trophic levels in FishBase of less than 3.25. This is in accord with the definition used by the SeaAroundUs project. For species with trophic levels between 3.25 and 3.5 I have used judgement as to whether they are important enough for fisheries to be included e.g. the Falkland sprat (Sprattus fuegensis) with a trophic level of 3.4 is included. As pointed out by Skjoldal (2011), reported trophic levels are only a rough approximation of the real position of an organism in a food-web at any time, so some flexibility in cut-offs is justified. Again, as with the size limit chosen, the trophic-level cut-off is somewhat arbitrary and has led to the exclusion of species some authorities would include as smaller “pelagic fish” and for which there are important fisheries e.g. Atlantic mackerel (Scomber scombrus), blue whiting (Micromestistius poutassou) and some of the flying fishes e.g. Hirundichthys affinis. The trophic level assigned to a species can also vary with the data source. For example, the multi-species foodweb model, Ecopath, will produce a table of trophic levels for each taxa for which diet preferences have been entered. These trophic levels can vary from the values given in FishBase because the two sets of trophic levels have been based on different sets of diet information. In addition, diet studies are missing for many of the species in FishBase, particularly from the tropics and sub-tropics, in these cases the trophic level has been estimated based upon the nearest related species.

The use of the term “forage fish” can also be criticised since nearly all smaller species are preyed upon by other (usually larger) predators in marine foodwebs. However, species considered to be “forage fish” often shoal in large numbers and it is this behaviour which increases their value as prey to other organisms and fisheries. Even the term “fish” is loosely applied with some authors including any animal which feeds low in the food-chain and provides an important trophic link to other predators. This definition can thus include a wide-range of invertebrates including krill (Pikitch et al. 2012b).

Because of these problems I have chosen to focus on marine (and estuarine) species generally regarded as pelagic (at least for a major part of their adult lives), where the species is known to play a key role in foodwebs and where the species has recorded marine fisheries. I have excluded species with maximum lengths > 50 cm or reported trophic levels of > 3.5 in FishBase. I have also not considered species caught predominantly in inland waters and have also excluded species which are reported as only “possibly” entering artisanal fisheries.
1.1. **Phylum Chordata; Class Osteichthyes**

In terms of taxonomic ordering, I have used alphabetical order based on scientific names rather than phylogenetic relationships. Different authors have also used different levels of families and orders so I have taken the current (Aug. 2013) information FishBase as being correct.

Many of the species commonly considered as SPF belong in the taxonomic order Clupeiformes. Whitehead (1983) listed all the known species of clupeoid fishes within four families, 80 genera and more than 300 species. In terms of geographical areas I have also chosen to exclude several semi-anadromous species whose range is largely limited to the Black, Caspian and Azov Seas on the basis that they are not fully marine. This has led to several commercially fished species being excluded, principally from the genus *Clupeonella* but the European sprat, *Sprattus sprattus*, being more marine has been included. Many semi-anadromous clupeoids, principally the shads, are found in other parts of the world and in the analysis of catch statistics it has not always been possible to fully separate the marine and freshwater catch components. Based on the SPF definition given above the report excludes species such as *Chirocentrus dorab* (the wolf herring) which predate on smaller schooling fish (and thus has a trophic level >4). I have also chosen to exclude species, such as the *Amblygasters*, which are recorded as only “probably” entering some artisanal fisheries. Whitehead et al. (1983) also noted that the identification of many sub-tropical and tropical Clupeoids to species level is difficult for the non-specialist so landings may not necessarily be recorded to the correct group. Species listing for the Clupeiformes can be found in Table 1.

Other SPF species come from the order Perciformes including members of the families Ammodytidae, Carangidae and Scombridae. These include the sandeels, jacks, scads and mackerels. Although most sandeels spend much of their lives buried in the sediment they do enter the water column as large schools to spawn and feed (Kooij *et al.* 2008). Although not considered truly pelagic, I have included them because many species of sandeel act as important foodweb linkages for the pelagic component of marine foodwebs. Within the Carangidae and Scombridae there are many species which have either higher trophic levels (>= 4), or larger maximum sizes than the arbitrary size limit chosen for this review – only the small to medium sized, lower trophic level species have been included - see Table 2.

In higher northern latitudes capelin are another important “forage” fish. These relatives of the salmonids (Order Salmoniformes, Family Osmeridae) are also considered by many authorities to be pelagic and so have been included. Other miscellaneous species with important fisheries which are sometimes included within the SPF category include blue whiting (*Micromestistius poutassou*) and Alaskan pollock (*Theragra chalcogramma*) (Skjoldal 2011). However, I have excluded the former on the basis of a reported trophic level of 4.0 and the latter on the basis of its reported maximum length being > 50 cm. Details for miscellaneous species are in Table 3.
1.2. Invertebrates

Nearly all the species of shrimp and prawns which are of interest to fisheries are not generally regarded as being “pelagic” (Holthius 1980). Species such as the northern shrimp, *Pandalus borealis*, do move up into the water column where they can be caught by mid-water trawling but the bulk of the catch now comes from demersal otter trawling (Aschan *et al.* 2012, Parsons *et al.* 2012). In contrast, there are important “pelagic” fisheries for euphausiids (krill). The main targets are *Euphausia superba* in the Southern Ocean and *E. pacifica* in the North Pacific. Although euphausiids are often quoted as being herbivorous, recent research clearly shows that a wider range of plankton are consumed (Haberman *et al.* 2003a, Martin *et al.* 2006, Schmidt 2010). For details see Table 4.

Globally, squid and cuttlefish have become increasingly important fisheries targets and some species have been included as “pelagics”. For example, the Pacific Management Council’s “Coastal Pelagic Species” list includes the market squid (*Loligo opalescens*). As in other areas (Overholtz *et al.* 2000), this species is an important prey for other fish, birds, and mammals. Squid are generally at a slightly higher trophic level than other plankton feeding SPF with significant amounts of fish in their diets (Ehrhardt 1991, Gasalla *et al.* 2010). For Antarctic species, crustacea such as euphausiids, do remain an important dietary component throughout their lives (Kear 1992). The quoted trophic levels (www.seaaroundus.org) for squid tend to be above 3.5 (*Sepia officianalis* 3.5; Sepiidae 3.6; *Illex argentinus* 3.8; *Loligo spp.* 4) so squid and cuttlefish have been excluded from this review (Pauly and Watson 2005).
### Table 1: Osteichthyes SPF species from the Order Clupeiformes

<table>
<thead>
<tr>
<th>Species [synonyms/subraces]</th>
<th>English name¹</th>
<th>Rec²</th>
<th>D³ (m)</th>
<th>L&lt;sub&gt;max&lt;/sub&gt;⁴ (cm)</th>
<th>TL⁵</th>
<th>A&lt;sub&gt;max&lt;/sub&gt;⁶ (yrs)</th>
<th>V⁷</th>
<th>Geographical range</th>
<th>Main fisheries</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anodontostoma chacunda</td>
<td>Chacunda gizzard shad</td>
<td>S</td>
<td>0-50</td>
<td>22.0</td>
<td>2.8</td>
<td>-</td>
<td>14</td>
<td>W. Pacific, Indian Ocean</td>
<td>Small-scale local</td>
</tr>
<tr>
<td>Brevoortia aurea</td>
<td>Brazilian menhaden</td>
<td>S</td>
<td>-</td>
<td>26.0</td>
<td>2.8</td>
<td>-</td>
<td>31</td>
<td>Brazil</td>
<td>Small-scale local</td>
</tr>
<tr>
<td>Brevoortia gunteri</td>
<td>Finescale menhaden*</td>
<td>-</td>
<td>0-50</td>
<td>30.0</td>
<td>2.4</td>
<td>-</td>
<td>35</td>
<td>Gulf of Mexico</td>
<td>Locally important</td>
</tr>
<tr>
<td>Brevoortia patronus</td>
<td>Gulf menhaden</td>
<td>S</td>
<td>0-50</td>
<td>35.0</td>
<td>2.2</td>
<td>-</td>
<td>31</td>
<td>Gulf of Mexico</td>
<td>Gulf of Mexico</td>
</tr>
<tr>
<td>Brevoortia pectinata</td>
<td>Argentine menhaden</td>
<td>S</td>
<td>5-?</td>
<td>35.0</td>
<td>3.4</td>
<td>-</td>
<td>39</td>
<td>SW. Atlantic</td>
<td>Small-scale local</td>
</tr>
<tr>
<td>Brevoortia tyrannus</td>
<td>Atlantic menhaden</td>
<td>S</td>
<td>0-50</td>
<td>50.0</td>
<td>2.3</td>
<td>-</td>
<td>30</td>
<td>NW Atlantic</td>
<td>Throughout range</td>
</tr>
<tr>
<td>Clupea harengus</td>
<td>Atlantic herring</td>
<td>S</td>
<td>0-200</td>
<td>45.0</td>
<td>3.2</td>
<td>25</td>
<td>32</td>
<td>W. and E. Atlantic</td>
<td>Throughout range</td>
</tr>
<tr>
<td>Clupea pallasi</td>
<td>Pacific herring</td>
<td>S</td>
<td>0-475</td>
<td>46.0</td>
<td>3.2</td>
<td>19</td>
<td>28</td>
<td>Arctic Sea, W. and E. Pacific</td>
<td>Throughout range</td>
</tr>
<tr>
<td>Ehirava fluviatilis</td>
<td>Malabar sprat</td>
<td>-</td>
<td>-</td>
<td>5.0</td>
<td>3.1</td>
<td>-</td>
<td>10</td>
<td>Southern India, Sri Lanka</td>
<td>Locally important</td>
</tr>
<tr>
<td>Escualosa thoracata</td>
<td>White sardine</td>
<td>-</td>
<td>0-50</td>
<td>10.0</td>
<td>3.2</td>
<td>1</td>
<td>13</td>
<td>N. Indian Ocean to NW. Australia</td>
<td>W. India, locally important</td>
</tr>
<tr>
<td>Ethmalosa fimbriata</td>
<td>Bonga shad</td>
<td>S</td>
<td>0-50</td>
<td>45.0</td>
<td>2.5</td>
<td>-</td>
<td>41</td>
<td>Central E. Atlantic</td>
<td>Senegal to Cameroon</td>
</tr>
<tr>
<td>Ethmidium maculatum</td>
<td>Pacific menhaden</td>
<td>S</td>
<td>0-50</td>
<td>26.0</td>
<td>2.1</td>
<td>-</td>
<td>31</td>
<td>SE. Pacific, Peru, Chile</td>
<td>Peru, Chile</td>
</tr>
<tr>
<td>Harengula clupeola</td>
<td>False herring</td>
<td>-</td>
<td>0-50</td>
<td>18.0</td>
<td>3.4</td>
<td>-</td>
<td>19</td>
<td>Central W. Atlantic</td>
<td>Small-scale local</td>
</tr>
<tr>
<td>Harengula humeralis</td>
<td>Redear herring</td>
<td>-</td>
<td>0-50</td>
<td>22.0</td>
<td>3.4</td>
<td>-</td>
<td>14</td>
<td>Central W. Atlantic</td>
<td>Small-scale local</td>
</tr>
<tr>
<td>Harengula jaguana</td>
<td>Scaled herring</td>
<td>-</td>
<td>?-22</td>
<td>21.2</td>
<td>3.3</td>
<td>3</td>
<td>21</td>
<td>New Jersey to Brazil</td>
<td>Small-scale local</td>
</tr>
<tr>
<td>Jenkinsia lamprotaeniæ³</td>
<td>Dwarf round herring</td>
<td>-</td>
<td>0-50</td>
<td>7.5</td>
<td>3.4</td>
<td>-</td>
<td>10</td>
<td>Central W. Atlantic</td>
<td>Small-scale local</td>
</tr>
<tr>
<td>Konosirus punctatus</td>
<td>Dotted gizzard shad</td>
<td>S</td>
<td>-</td>
<td>32.0</td>
<td>2.9</td>
<td>-</td>
<td>36</td>
<td>NW. Pacific, Japan, Yellow Sea</td>
<td>Ariake Sound, other areas?</td>
</tr>
<tr>
<td>Nematalosa japonica</td>
<td>Japanese gizzard shad</td>
<td>-</td>
<td>-</td>
<td>19.0</td>
<td>2.4</td>
<td>-</td>
<td>24</td>
<td>W. Pacific, Sea of Japan</td>
<td>Locally important</td>
</tr>
<tr>
<td>Nematalosa nasus</td>
<td>Bloch’s gizzard shad</td>
<td>S</td>
<td>0-30</td>
<td>22.0</td>
<td>2.7</td>
<td>-</td>
<td>22</td>
<td>Indo-west Pacific, S. China Sea</td>
<td>Small-scale local</td>
</tr>
<tr>
<td>Opisthonomia libertate</td>
<td>Pacific thread herring</td>
<td>S</td>
<td>50-?</td>
<td>30.0</td>
<td>2.9</td>
<td>-</td>
<td>25</td>
<td>Central Eastern Pacific</td>
<td>Central Eastern Pacific</td>
</tr>
<tr>
<td>Opisthonomia medirastre</td>
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<td>7</td>
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<td>Throughout range</td>
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<td>Deepbody sardinella</td>
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² In the UK smaller S. pilchardus are called sardines and larger fish pilchards. Generally the common name sardine and pilchard are inter-changeable.

---

[12]
<table>
<thead>
<tr>
<th>Species [synonyms/subraces]</th>
<th>English name¹</th>
<th>Rec²</th>
<th>D³ (m)</th>
<th>Lmax⁴ (cm)</th>
<th>TL⁵</th>
<th>Amax * (yrs)</th>
<th>V⁷</th>
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<th>Main fisheries</th>
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<td>-</td>
<td>10</td>
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<td>S. India locally important</td>
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<td>7</td>
<td>10</td>
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<td>Indonesia, S. India</td>
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<td>2.5</td>
<td>-</td>
<td>18</td>
<td>E. Indian Ocean, W. Pacific</td>
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<td>Sardinella longiceps</td>
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<td>Spratelloides gracilis</td>
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<td>10</td>
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<td>Sprattus antipodum</td>
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<td>3.4</td>
<td>-</td>
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<td>2.7</td>
<td>-</td>
<td>26</td>
<td>SE Pacific, Chile</td>
<td>Chile</td>
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</table>

ORDER: Clupeiformes ; FAMILY: Dussumieriidae

| Dussumieria acuta | Rainbow sardine | S | 10-20 | 20.0 | 3.4 | - | 14 | Indo-Pacific to W. Pacific | Japan, S. Africa, Indonesia, Philippines |
| Dussumieria elopsoides | Slender rainbow sardine | S | 0-50 | 20.0 | 3.4 | - | 24 | Indo-Pacific to W. Pacific | Japan, S. Africa, Indonesia, Philippines |
| Etrumeus teres {sadina}⁴ | Red-eye round herring | S | 0-150 | 33.0 | 3.5 | - | 33 | Indo-Pacific to W. Pacific | NW. Pacific |
| Etrumeus whiteheadi | Whitehead’s round herring | S | 0-200 | 22.0 | 3.4 | - | 21 | SE. Atlantic to W. Indian Ocean, S. Africa | SE. Atlantic |

ORDER: Clupeiformes ; FAMILY: Pristigasteridae

| Ilisha africana | West African ilisha | S | 0-25 | 30.0 | 3.4 | - | 19 | W. Africa | Small-scale local |
| Ilisha filigera | Coromandel ilisha | - | 0-50 | 22.0 | 3.4 | - | 18 | Indian Ocean, S. China Sea | Small-scale local |

³ The common names pilchard and sardine are interchangeable – thus different papers use S. American pilchard, S. American sardine, Japanese pilchard, Japanese sardine etc.
⁴ World Register of Marine Species shows *Etrumeus teres* as accepted synonym whereas FishBase uses *Etrumeus sadina*
<table>
<thead>
<tr>
<th>Species [synonyms/subraces]</th>
<th>English name¹</th>
<th>Rec²</th>
<th>D’ (m)</th>
<th>Lₘₐₓ¹ (cm)</th>
<th>TLₜ²</th>
<th>Aₘₐₓ³ (yrs)</th>
<th>V⁴</th>
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<th>Main fisheries</th>
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<td>-</td>
<td>23</td>
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<td>May be locally important?</td>
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<td>3.5</td>
<td>-</td>
<td>13</td>
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</tr>
<tr>
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<td>Lobejaw ilisha</td>
<td>-</td>
<td>0-50</td>
<td>23.0</td>
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<td>-</td>
<td>15</td>
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<td>-</td>
<td>-</td>
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<td>-</td>
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*ORDER: Clupeiformes; FAMILY: Engraulidae³*

<table>
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<th>TLₜ²</th>
<th>Aₘₐₓ³ (yrs)</th>
<th>V⁴</th>
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<th>Main fisheries</th>
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<td>-</td>
<td>13</td>
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<tr>
<td><em>Anchoa compressa</em></td>
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<td>3.4</td>
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<td>15</td>
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<tr>
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<td>3.4</td>
<td>-</td>
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<tr>
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<td>3.3</td>
<td>-</td>
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<td>-</td>
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<td>3.4</td>
<td>-</td>
<td>10</td>
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<td>TL(^5)</td>
<td>A(_{\text{max}})^6 (yrs)</td>
<td>V(^7)</td>
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<td>NE, and central E Atlantic, Mediterranean, W. Africa</td>
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<td>4</td>
<td>15</td>
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<td>30</td>
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<td>17</td>
<td>SE Pacific, Peru, Chile</td>
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</tr>
<tr>
<td><em>Setipinna breviceps</em></td>
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</tr>
<tr>
<td><em>Setipinna phasa</em></td>
<td>Gangetic hairfin anchovy</td>
<td>-</td>
<td>-</td>
<td>40.0</td>
<td>3.3</td>
<td>-</td>
<td>39</td>
<td>Indian estuaries</td>
<td>Locally important</td>
</tr>
<tr>
<td><em>Setipinna taty</em></td>
<td>Scaly hairfin anchovy</td>
<td>-</td>
<td>0-50</td>
<td>15.3</td>
<td>3.2</td>
<td>-</td>
<td>32</td>
<td>Indian Ocean, Central W. Pacific</td>
<td>Artisanal catches</td>
</tr>
<tr>
<td><em>Stolephorus chinensis</em></td>
<td>China anchovy</td>
<td>-</td>
<td>0-50</td>
<td>9.0</td>
<td>3.3</td>
<td>-</td>
<td>11</td>
<td>W. Pacific</td>
<td>Part of clupeoid catches?</td>
</tr>
<tr>
<td><em>Stolephorus commersonii</em></td>
<td>Commerson’s anchovy</td>
<td>-</td>
<td>0-50</td>
<td>10.0</td>
<td>3.1</td>
<td>-</td>
<td>14</td>
<td>Indian Ocean, W. Pacific</td>
<td>Part of clupeoid catches?</td>
</tr>
<tr>
<td><em>Stolephorus waitei</em></td>
<td>Spotty-face anchovy</td>
<td>-</td>
<td>0-50</td>
<td>9.4</td>
<td>3.3</td>
<td>-</td>
<td>42</td>
<td>Indian Ocean, W. Pacific</td>
<td>Part of clupeoid catches?</td>
</tr>
<tr>
<td><em>Thryssa baelama</em></td>
<td>Balaema anchovy</td>
<td>-</td>
<td>0-50</td>
<td>16.0</td>
<td>2.9</td>
<td>-</td>
<td>18</td>
<td>Indian Ocean, Central W. Pacific</td>
<td>Part of clupeoid catches?</td>
</tr>
<tr>
<td><em>Thryssa gautamiensis</em></td>
<td>Gautama thryssa*</td>
<td>-</td>
<td>0-50</td>
<td>21.5</td>
<td>3.3</td>
<td>-</td>
<td>25</td>
<td>W. Indian Ocean</td>
<td>Artisanal catches</td>
</tr>
<tr>
<td><em>Thryssa hamiltonii</em></td>
<td>Hamilton’s thryssa</td>
<td>-</td>
<td>10-13</td>
<td>27.0</td>
<td>3.5</td>
<td>-</td>
<td>16</td>
<td>Indian Ocean, W. Pacific</td>
<td>Artisanal catches</td>
</tr>
<tr>
<td><em>Thryssa malabarica</em></td>
<td>Malabar thryssa</td>
<td>-</td>
<td>0-50</td>
<td>17.5</td>
<td>3.3</td>
<td>-</td>
<td>21</td>
<td>Indian Ocean</td>
<td>Artisanal catches</td>
</tr>
<tr>
<td><em>Thryssa setirostris</em></td>
<td>Longjaw thryssa</td>
<td>-</td>
<td>1-20</td>
<td>18.0</td>
<td>3.3</td>
<td>-</td>
<td>21</td>
<td>Indian Ocean, W. Pacific</td>
<td>Part of clupeoid catches?</td>
</tr>
<tr>
<td><em>Thryssa vitrirostris</em></td>
<td>Orangemouth anchovy</td>
<td>-</td>
<td>0-50</td>
<td>20.0</td>
<td>3.3</td>
<td>-</td>
<td>24</td>
<td>Indian Ocean</td>
<td>May be locally important?</td>
</tr>
</tbody>
</table>

\(^1\) English name according to FAO ASFIS table, English names marked with an asterisk (*) are from Fishbase where the species is not listed in ASFIZ. FAO Landings database also includes some landings records as “Anchovies, etc. nei.”.  
\(^2\) FAO landings records; S = Species level landings records available in FAO database (see section 2 of this report), A = landings data aggregated to higher taxa resolution, - = no records available for this species (excludes any inland waters landings).  
\(^3\) Reported depth range (FishBase).  
\(^4\) Maximum reported size as standard length.  
\(^5\) Trophic level - some trophic levels are estimated based on size and diet of closest relatives – see individual species in FishBase for details.  
\(^6\) Maximum reported age, - = not available  
\(^7\) Vulnerability index (out of 100) calculated according to (Cheung et al. 2005, Cheung et al. 2007).  

\(^8\) Trophic index appears skewed upwards by single record of 100% detritus in diet, all other references for this species suggest a trophic level of between 2.3-3.2  
Sources: FishBase, (Whitehead 1983), (Whitehead et al. 1988, Frimodt 1995a, b)
Table 2: Osteichthyes SPF species from the order Perciformes

<table>
<thead>
<tr>
<th>Species [synonyms/subraces]</th>
<th>English name(^1)</th>
<th>Rec(^2)</th>
<th>D(^1) (m)</th>
<th>L(_{\text{max}}) (^4) (cm)</th>
<th>TL(^5)</th>
<th>A(_{\text{max}}) (^6) (yrs)</th>
<th>V(^7)</th>
<th>Geographical range</th>
<th>Main fisheries</th>
</tr>
</thead>
<tbody>
<tr>
<td>ORDER: Perciformes; FAMILY: Ammodytidae</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Ammodytes americanus</td>
<td>American sand lance</td>
<td>A</td>
<td>0-73</td>
<td>23.5</td>
<td>3.2</td>
<td>-</td>
<td>28</td>
<td>NW. Atlantic</td>
<td>Small-scale local</td>
</tr>
<tr>
<td>Ammodytes dubius</td>
<td>Northern sand lance</td>
<td>A</td>
<td>0-108</td>
<td>25.0</td>
<td>3.1</td>
<td>-</td>
<td>33</td>
<td>N. Atlantic</td>
<td>Reported to be of potential interest</td>
</tr>
<tr>
<td>Ammodytes hexapterus(^3)</td>
<td>Pacific sand lance*</td>
<td>S</td>
<td>30-100</td>
<td>30.0</td>
<td>3.1</td>
<td>11</td>
<td>31</td>
<td>Arctic, NW. to NE. Pacific</td>
<td>Locally important</td>
</tr>
<tr>
<td>Ammodytes marinus</td>
<td>Lesser sand-eel</td>
<td>A</td>
<td>10-150</td>
<td>25.0</td>
<td>2.7</td>
<td>10</td>
<td>30</td>
<td>NE. Atlantic and Baltic</td>
<td>North Sea, Irish Sea</td>
</tr>
<tr>
<td>Ammodytes personatus</td>
<td>Pacific sand lance</td>
<td>S</td>
<td>-</td>
<td>15.0</td>
<td>3.1</td>
<td>-</td>
<td>26</td>
<td>NW. Pacific and Alaska</td>
<td>Japan</td>
</tr>
<tr>
<td>Ammodytes tobianus</td>
<td>Small sandeel</td>
<td>A</td>
<td>1-96</td>
<td>20.0</td>
<td>3.1</td>
<td>7</td>
<td>23</td>
<td>NE. Atlantic and Baltic</td>
<td>North Sea, Irish Sea</td>
</tr>
<tr>
<td>Gymnammodytes semisquamatus</td>
<td>Smooth sandeel</td>
<td>A</td>
<td>-</td>
<td>30.0</td>
<td>2.7</td>
<td>-</td>
<td>41</td>
<td>NE. Atlantic excluding Baltic</td>
<td>Reported as a by-catch</td>
</tr>
<tr>
<td>ORDER: Perciformes; FAMILY: Carangidae</td>
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</tr>
<tr>
<td>Alepes melanoptera</td>
<td>Blackfin scad</td>
<td>-</td>
<td>-</td>
<td>25.0</td>
<td>3.4</td>
<td>-</td>
<td>17</td>
<td>Indo-Pacific</td>
<td>Minor commercial</td>
</tr>
<tr>
<td>Chloroscombrus orqueta</td>
<td>Pacific bumper</td>
<td>S</td>
<td>-</td>
<td>30.0</td>
<td>2.5</td>
<td>-</td>
<td>23</td>
<td>E. Pacific</td>
<td>Commercial</td>
</tr>
<tr>
<td>Decapterus aakaadsi</td>
<td>Scad*</td>
<td>-</td>
<td>-</td>
<td>30.0</td>
<td>3.4</td>
<td>-</td>
<td>28</td>
<td>W. Pacific, Japan</td>
<td>Commercial</td>
</tr>
<tr>
<td>Decapterus koheru</td>
<td>Koheru*</td>
<td>-</td>
<td>-</td>
<td>40.0</td>
<td>3.1</td>
<td>-</td>
<td>27</td>
<td>N. Zealand</td>
<td>Minor commercial</td>
</tr>
<tr>
<td>Decapterus macarellus</td>
<td>Mackerel scad</td>
<td>-</td>
<td>40-200</td>
<td>46.0</td>
<td>3.4</td>
<td>-</td>
<td>23</td>
<td>Circumglobal, central to mid lat.</td>
<td>Commercial</td>
</tr>
<tr>
<td>Decapterus macrosoma</td>
<td>Shortfin scad</td>
<td>S</td>
<td>20-214</td>
<td>35.0</td>
<td>3.4</td>
<td>-</td>
<td>24</td>
<td>Indo-west Pacific, E. Pacific</td>
<td>Commercial</td>
</tr>
<tr>
<td>Decapterus maruadsi</td>
<td>Japanese scad</td>
<td>S</td>
<td>0-20</td>
<td>25.0</td>
<td>3.4</td>
<td>-</td>
<td>17</td>
<td>Indo-west Pacific</td>
<td>Japan</td>
</tr>
<tr>
<td>Decapterus muroadsi</td>
<td>Amberstripe scad</td>
<td>-</td>
<td>1-320</td>
<td>50.0</td>
<td>3.4</td>
<td>-</td>
<td>39</td>
<td>E. Atlantic, Indo-west Pacific</td>
<td>Small-scale commercial</td>
</tr>
<tr>
<td>Decaptorus tabl</td>
<td>Roughbass scad</td>
<td>-</td>
<td>7-400</td>
<td>50.0</td>
<td>3.2</td>
<td>-</td>
<td>32</td>
<td>Pacific, Austalia, W. Atlantic</td>
<td>Minor commercial</td>
</tr>
<tr>
<td>Hemicaranx amblonychus</td>
<td>Blunt-nose jack</td>
<td>-</td>
<td>-</td>
<td>50.0</td>
<td>3.1</td>
<td>-</td>
<td>32</td>
<td>Central W. Atlantic to Brazil</td>
<td>Small-scale local</td>
</tr>
<tr>
<td>Selene orstedii</td>
<td>Mexican moonfish</td>
<td>-</td>
<td>-</td>
<td>33.0</td>
<td>3.3</td>
<td>-</td>
<td>24</td>
<td>E. Pacific</td>
<td>Minor commercial</td>
</tr>
<tr>
<td>Trachurus japonicus</td>
<td>Japanese jack mackerel</td>
<td>S</td>
<td>0-275</td>
<td>50.0</td>
<td>3.4</td>
<td>12</td>
<td>32</td>
<td>NW. Pacific</td>
<td>Japan, Korea</td>
</tr>
<tr>
<td>Trachurus novaezelandiae</td>
<td>Yellowtail horse mackerel</td>
<td>-</td>
<td>22-500</td>
<td>50.0</td>
<td>3.2</td>
<td>25</td>
<td>38</td>
<td>Australia, New Zealand</td>
<td>Commercial</td>
</tr>
<tr>
<td>Trachurus trecae</td>
<td>Cunene horse mackerel</td>
<td>S</td>
<td>20-100</td>
<td>35.0</td>
<td>3.5</td>
<td>-</td>
<td>36</td>
<td>Central E. Atlantic</td>
<td>Angola</td>
</tr>
<tr>
<td>ORDER: Perciformes; FAMILY: Scombridae</td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rastrelliger brachysoma</td>
<td>Short mackerel</td>
<td>A</td>
<td>15-200</td>
<td>34.5</td>
<td>2.7</td>
<td>-</td>
<td>18</td>
<td>Central Indo-west Pacific</td>
<td>Locally important</td>
</tr>
<tr>
<td>Rastrelliger jaugni</td>
<td>Island mackerel</td>
<td>A</td>
<td>150-?</td>
<td>20.0</td>
<td>3.4</td>
<td>-</td>
<td>11</td>
<td>Indo-west Pacific</td>
<td>Commercial</td>
</tr>
<tr>
<td>Rastrelliger kanagurta</td>
<td>Indian mackerel</td>
<td>S</td>
<td>20-90</td>
<td>35.0</td>
<td>3.2</td>
<td>-</td>
<td>18</td>
<td>Indo-west Pacific</td>
<td>Throughout range</td>
</tr>
</tbody>
</table>
1 English name according to FAO ASFIS table, English names marked with an asterisk (*) are from Fishbase where the species is not listed in ASFIZ. FAO Landings database groups N. Atlantic sandeels as “Sandeels(=Sandalances) nei”; Some landings for the smaller scads may be included in group “scads nei” but it is not possible to separate these to species level. 2FAO landings records; S = Species level landings records available in FAO database (see section 2 of this report), A = landings data aggregated, - = no records available for this species (excludes any inland waters landings). 3Reported depth range (FishBase). 4Maximum reported size as fork length for the Scombridae, total length for other families. 5Trophiic level - some trophic levels are estimated based on size and diet of closest relatives – see individual species in FishBase for details. 6Maximum reported age, - = not available. 7Vulnerability index (out of 100) calculated according to (Cheung et al. 2005, Cheung et al. 2007).

$^8$Two species are identified as Pacific sandlance in FishBase but only A. personatus is listed in ASFIS. $^5^5$Diet of adults appears to contain more small fish and cephalopods compared with S. japonicus but landings statistics combine the two groups. $^5^5^5$In Collette et al. (1983) this species was grouped with S. japonicus. The taxonomy has recently been revised on the basis of molecular data which recognises four distinct Scomber species (Collette 1999, Infante et al. 2007). However FAO landings statistics group S. colias and S. japonicus together.

### Table 3: Miscellaneous Osteichthyes SPF species

<table>
<thead>
<tr>
<th>Species [synonyms/subraces]</th>
<th>English name¹</th>
<th>Rec²</th>
<th>D³ (m)</th>
<th>L₄ max⁴ (cm)</th>
<th>TL⁵</th>
<th>A₆ max⁶ (yrs)</th>
<th>V⁷</th>
<th>Geographical range</th>
<th>Main fisheries</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>ORDER: Atheriniformes; FAMILY: Atherinidae</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Atherina hepsetus</td>
<td>Mediterranean sand smelt</td>
<td>S</td>
<td>-</td>
<td>20.0</td>
<td>3.2</td>
<td>-</td>
<td>31</td>
<td>E. Atlantic, W. Mediterranean</td>
<td>Throughout range?</td>
</tr>
<tr>
<td>Atherinomorus lacunosus</td>
<td>Hardyhead silverside</td>
<td>-</td>
<td>1-39</td>
<td>25.0</td>
<td>3.3</td>
<td>-</td>
<td>34</td>
<td>Indo-Pacific</td>
<td>Small-scale local</td>
</tr>
<tr>
<td>Atherinomorus ogilbyi</td>
<td>Ogilby’s hardyhead*</td>
<td>-</td>
<td>-</td>
<td>17.0</td>
<td>3.2</td>
<td>-</td>
<td>29</td>
<td>W. and E. Australia</td>
<td>Minor commercial</td>
</tr>
<tr>
<td><strong>ORDER: Beloniformes; FAMILY: Exocoetidae</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cheilopogon agoo</td>
<td>Japanese flying fish</td>
<td>S</td>
<td>0-?</td>
<td>35.0</td>
<td>3.4</td>
<td>-</td>
<td>22</td>
<td>NW. Pacific</td>
<td>Japan</td>
</tr>
<tr>
<td>Cheilopogon exsiliens</td>
<td>Bandwing flying fish*</td>
<td>A</td>
<td>0-20</td>
<td>30.0</td>
<td>3.0</td>
<td>-</td>
<td>17</td>
<td>W. Atlantic excl. Caribbean</td>
<td>Small-scale local</td>
</tr>
<tr>
<td>Cheilopogon heterurus</td>
<td>Mediterranean flying fish*</td>
<td>A</td>
<td>-</td>
<td>40.0</td>
<td>3.4</td>
<td>-</td>
<td>21</td>
<td>E. Atlantic, W. Mediterranean, W. Atlantic and sub-tropical Pacific</td>
<td>Reported of potential interest</td>
</tr>
<tr>
<td>Exocoetus monocirrhus</td>
<td>Barbel flying fish</td>
<td>A</td>
<td>0-20</td>
<td>20.0</td>
<td>3.1</td>
<td>-</td>
<td>13</td>
<td>Indo-Pacific, E. Pacific</td>
<td>Minor commercial</td>
</tr>
<tr>
<td>Exocoetus volitans</td>
<td>Tropical two-wing flying fish</td>
<td>A</td>
<td>0-20</td>
<td>30.0</td>
<td>3.0</td>
<td>-</td>
<td>17</td>
<td>Throughout tropics and sub-tropics</td>
<td>Throughout range?</td>
</tr>
<tr>
<td>Fodiator acutus</td>
<td>Sharpchin flying fish</td>
<td>A</td>
<td>0-?</td>
<td>18.0</td>
<td>3.3</td>
<td>-</td>
<td>10</td>
<td>Central E. Atlantic</td>
<td>Locally important</td>
</tr>
<tr>
<td>Hirundichys speculiger</td>
<td>Mirrorwing flying fish*</td>
<td>A</td>
<td>0-20</td>
<td>30.0</td>
<td>3.0</td>
<td>-</td>
<td>17</td>
<td>Worldwide tropical</td>
<td>Minor commercial</td>
</tr>
<tr>
<td>Parexocoetus brachypterus</td>
<td>Sailfin flying fish</td>
<td>A</td>
<td>0-20</td>
<td>20.0</td>
<td>3.4</td>
<td>-</td>
<td>10</td>
<td>Indo-Pacific, W. Atlantic, Caribbean, Central E. Atlantic</td>
<td>Minor commercial</td>
</tr>
<tr>
<td>Parexocoetus mento</td>
<td>African sailfin flying fish</td>
<td>A</td>
<td>0-20</td>
<td>11.0</td>
<td>3.3</td>
<td>-</td>
<td>10</td>
<td>Indo-Pacific to Australia, E. Mediterranean (via Suez Canal)</td>
<td>Minor commercial</td>
</tr>
<tr>
<td><strong>ORDER: Beloniformes; FAMILY: Hemiramphidae</strong></td>
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<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Hemiramphus archipelagicus</td>
<td>Jumping halfbeak</td>
<td>A</td>
<td>-</td>
<td>34.0</td>
<td>3.3</td>
<td>-</td>
<td>22</td>
<td>Indo-Pacific, W. Polynesia</td>
<td>Minor commercial</td>
</tr>
<tr>
<td>Hemiramphus balao</td>
<td>Balao halfbeak</td>
<td>A</td>
<td>5 - ?</td>
<td>40.0</td>
<td>3.6⁸</td>
<td>-</td>
<td>18</td>
<td>Central W. Atlantic, E. Atlantic</td>
<td>Small-scale local</td>
</tr>
<tr>
<td>Hemiramphus brasiliensis</td>
<td>Ballyhoo halfbeak</td>
<td>S</td>
<td>? - 5</td>
<td>55.0</td>
<td>2.5</td>
<td>-</td>
<td>27</td>
<td>Central W. Atlantic, E. Atlantic</td>
<td>Minor commercial</td>
</tr>
<tr>
<td>Hemiramphus convexus</td>
<td>-</td>
<td>A</td>
<td>-</td>
<td>23.0</td>
<td>3.0</td>
<td>-</td>
<td>13</td>
<td>Indo-west Pacific</td>
<td>Minor commercial</td>
</tr>
<tr>
<td>Hemiramphus far</td>
<td>Black-barred halfbeak</td>
<td>A</td>
<td>-</td>
<td>45.0</td>
<td>2.9</td>
<td>-</td>
<td>26</td>
<td>Indo-west Pacific, E. Mediterranean</td>
<td>Small-scale local</td>
</tr>
</tbody>
</table>

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<table>
<thead>
<tr>
<th>Species [synonyms/subraces]</th>
<th>English name(^1)</th>
<th>Rec(^2)</th>
<th>D(^3) (m)</th>
<th>L(_{\text{max}})(^4) (cm)</th>
<th>TL(^5)</th>
<th>A(_{\text{max}})(^6) (yrs)</th>
<th>V(^7)</th>
<th>Geographical range</th>
<th>Main fisheries</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hemiramphus lutkei(^2)</td>
<td>Lutke’s halfbeak</td>
<td>A</td>
<td>-</td>
<td>40.0</td>
<td>3.3</td>
<td>-</td>
<td>31</td>
<td>Pacific Ocean</td>
<td>Small-scale local</td>
</tr>
<tr>
<td>Hemiramphus marginatus</td>
<td>Yellowtip halfbeak</td>
<td>A</td>
<td>-</td>
<td>26.0</td>
<td>3.2</td>
<td>-</td>
<td>21</td>
<td>W. Indian Ocean</td>
<td>Small-scale local</td>
</tr>
<tr>
<td>Hyporhamphus dussumieri</td>
<td>Dussumier’s halfbeak*</td>
<td>A</td>
<td>-</td>
<td>38.0</td>
<td>3.5</td>
<td>-</td>
<td>30</td>
<td>Indo-Pacific</td>
<td>Small-scale local</td>
</tr>
<tr>
<td>Hyporhamphus ihi</td>
<td>New Zealand garfish*</td>
<td>A</td>
<td>-</td>
<td>26.0</td>
<td>3.2</td>
<td>-</td>
<td>21</td>
<td>New Zealand</td>
<td>Minor commercial</td>
</tr>
<tr>
<td>Hyporhamphus limbatis</td>
<td>Congatturi halfbeak</td>
<td>A</td>
<td>-</td>
<td>35.0</td>
<td>3.1</td>
<td>-</td>
<td>20</td>
<td>Indo-west Pacific</td>
<td>Small-scale local</td>
</tr>
<tr>
<td>Hyporhamphus quoiyi</td>
<td>Quoy’s garfish*</td>
<td>A</td>
<td>-</td>
<td>31.2</td>
<td>3.0</td>
<td>-</td>
<td>25</td>
<td>Indo-west Pacific, N. Australia</td>
<td>Small-scale local</td>
</tr>
<tr>
<td>Hyporhamphus roberti</td>
<td>Slender halfbeak</td>
<td>A</td>
<td>-</td>
<td>32.0</td>
<td>3.0</td>
<td>-</td>
<td>21</td>
<td>Central W. Atlantic</td>
<td>Minor commercial</td>
</tr>
<tr>
<td>Hyporhamphus sajori</td>
<td>Japanese halfbeak</td>
<td>S</td>
<td>30-70</td>
<td>40.0</td>
<td>3.4</td>
<td>-</td>
<td>25</td>
<td>NW. Pacific</td>
<td>Commercial</td>
</tr>
<tr>
<td>Hyporhamphus unifasciatus</td>
<td>Common halfbeak*</td>
<td>A</td>
<td>0-5</td>
<td>30.0</td>
<td>2.0</td>
<td>-</td>
<td>15</td>
<td>W. Atlantic, Caribbean, S. America</td>
<td>Venezuela, small-scale local</td>
</tr>
<tr>
<td><strong>Rhynchorchamphus georgii</strong></td>
<td>Long billed halfbeak</td>
<td>A</td>
<td>-</td>
<td>31.0</td>
<td>3.0</td>
<td>-</td>
<td>15</td>
<td>Indo-west Pacific, N. Australia</td>
<td>Minor commercial</td>
</tr>
</tbody>
</table>

**ORDER: Gasterosteiformes; FAMILY: Hypotychidae**

| Hypoptychus dybowskii     | Korean sand lance   | S       | Na       | 10.0            | 3.3  | 1               | 10   | N. Pacific      | Limited commercial |

**ORDER: Osmeriformes; FAMILY: Osmeridae**

| Hypomesus pretiosus       | Surf smelt          | A       | -        | 30.5            | 3.4  | 5               | 31   | E. Pacific      | Small-scale local |
| Mallotus villosus         | Capelin             | S       | 0-725    | 20.0            | 3.2  | 10              | 23   | Arctic and N. Atlantic | Throughout range |
| Osmerus eperlanus         | European smelt      | S       | 2-50     | 45.0            | 3.0  | 10              | 43   | N. Atlantic incl. Baltic | Catch mostly from inland waters |
| Osmerus mordax mordax     | Rainbow smelt       | S       | 0-425    | 35.6            | 3.0  | -               | 38   | N. Atlantic, NW. Pacific | Limited commercial |
| Spirinchus starksi        | Night smelt*        | A       | -        | 23.0            | 3.5  | 3               | 16   | NE. Pacific     | Limited commercial |
| Thaleichthys pacificus    | Eulachon            | A       | 0-300    | 34.0            | 3.3  | 5               | 33   | N. Pacific      | Limited commercial |

\(^1\) English name according to FAO ASFIS table, English names marked with an asterisk (*) are from Fishbase where the species is not listed in ASFIZ. \(^2\)FAO landings records; S = Species level landings records available in FAO database (see section 2 of this report), A = landings data aggregated, - = no records available for this species (excludes any inland waters landings). \(^3\)Reported depth range (FishBase). \(^4\)Maximum reported size as total length (FishBase). \(^5\)Trophic level - some trophic levels are estimated based on size and diet of closest relatives – see individual species in FishBase for details. \(^6\)Maximum reported age, - = not available. \(^7\)Vulnerability index (out of 100) calculated according to (Cheung et al. 2005, Cheung et al. 2007).
The FAO landings database contains few species level records for flying fishes and halfbeaks so the aggregated categories “Flying fishes nei” and “Halfbeaks nei” have been used. Also landings of smelts recorded as “Smelts nei” in addition to species level records. Small amount of landings recorded in FAO database for *S. saurus* from SE. Pacific (Chile, fishing area Pacific south-east) are presumably mis-records for the Pacific saury, *Cololabis sauris*.

Sources: FishBase, (Frimodt 1995a, b, Carpenter et al. 1997)
Table 4: Invertebrate SPF species

<table>
<thead>
<tr>
<th>Species [synonyms/subraces]</th>
<th>English name(^1)</th>
<th>Rec(^2)</th>
<th>D(^3) (m)</th>
<th>L(_{\text{max}})(^4) (cm)</th>
<th>TL(^5)</th>
<th>A(_{\text{max}})(^6) (yrs)</th>
<th>V(^7)</th>
<th>Geographical range</th>
<th>Main fisheries</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>ORDER: Euphausiacea; FAMILY: Euphausiidae</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Euphausia superba</em></td>
<td>Antarctic krill</td>
<td>S</td>
<td>0-500</td>
<td>6-7</td>
<td>2.2</td>
<td>5-7</td>
<td>-</td>
<td>Circum-Antarctic</td>
<td>Antarctic</td>
</tr>
<tr>
<td><em>Euphausia pacifica</em></td>
<td>Pacific krill</td>
<td>-</td>
<td>0-300</td>
<td>2</td>
<td>1-2</td>
<td>-</td>
<td>-</td>
<td>N. Pacific</td>
<td>Japan, British Columbia</td>
</tr>
<tr>
<td><em>Meganyctiphanes norvegica</em></td>
<td>Norwegian krill</td>
<td>S</td>
<td>0-300</td>
<td>4</td>
<td>2+</td>
<td>-</td>
<td>-</td>
<td>N. Atlantic</td>
<td>N. Atlantic</td>
</tr>
</tbody>
</table>

\(^1\) English name according to FAO ASFIS table  
\(^2\) FAO landings records; S = Species level landings records available in FAO database (see section 2 of this report), A = landings data aggregated to higher taxa resolution, - = no records available for this species  
\(^3\) Reported depth range  
\(^4\) Maximum reported size as total length  
\(^5\) Trophic level from the Large-Marine Ecoystem, Marine Trophic Index (www.seaaroundus.org)  
\(^6\) Maximum reported age  
\(^7\) Vulnerability index (out of 100) calculated according to (Cheung et al. 2005, Cheung et al. 2007). CHECK WHAT THIS REALLY MEANS

Sources: (Nicol and Endo 1997)
2. Trends in global catches for small-pelagic fish

Landings records for the species listed in Section 1 were extracted from the FAO Global Capture Production Dataset (1950-2011) using FishStatJ. Scientific names were cross-referenced with English names based on the ASFIS table (http://www.fao.org/knowledge/documents-detail/en/c/128444/?type=list). In a few cases, as noted below, it was possible to disaggregate landings data to the species level so that some non-SPF species may be included. In some cases catches in the database are estimated by FAO (these are tagged F in FAO FishStat) but these estimates have been treated in the same manner as the other landings records in this review.

In the text of this report the words “catch” and “landings” have been used interchangeably. Although it is generally not advisable to do this where significant levels of discarding occur (in which cases “catch” will exceed reported “landings”) but for most SPF fisheries, discard levels are usually regarded as being minimal. Many of the species listed below are caught in small-scale fisheries (often for use as bait) and reliable catch data will often be missing. Even though the value per unit weight of SPF is often low, IUU (Illegal, unreported and unregulated) fishing can still affect SPF stocks (MRAG 2008). In some fisheries discarding of SPF in favour of landing more valuable species, such as prawns, has also been reported (Dalzell 1993). FAO landings/catch data should therefore be regarded as indicating the minimum amounts of fish harvested.

Throughout this report the symbol “Mt” means “millions of tonnes” and “Kt” means “thousands of tonnes”, a tonne is 1000 kg. Fish landings are assumed to be expressed as wet weight.

2.1. Global trends in landings by family

Global landings of SPF are shown in Figure 1 and Table 5. Three major periods can be identified across the whole time-series which run from 1950 to 2011. In 1950 just over 4 million tonnes (Mt) of SPF were being landed annually but this increased significantly from 1958 onwards due to major increases in the catches of Engraulids. A peak was reached in 1970 at just over 22 Mt but this was followed by a rapid decline. There followed a period of gradual significant increase driven by increased landings of clupeids with total landings reaching over 26 Mt in 1990. Around this time, the proportion of clupeids in the total fell, but at the same time catches of engraulids increased again. The peak of SPF landings was in 1994 at around 27 Mt. Since then there is evidence of a slow decline although there was a short-lived sudden drop in 1998. Recent SPF landings have been fluctuating around the 18 to 22 Mt level. Over the whole period the total landings have been 1,115 Mt.

Across the time-series, clupeids have contributed a little more to the landings compared with engraulids (Table 5). Most of the short-term volatility in total SPF landings is due to fluctuations in the catches of engraulids and this is discussed in later sections of this review. Catches of clupeids appear to change more smoothly although may be masking more rapid changes for individual species. Members of the Osmeridae have at times also
contributed notably to overall landings, for example in the period 1972-1985, but their contribution has been much smaller in recent years. All other groups combined have provided a relatively small (≈ 10%), but often locally important, contribution to the overall landings (Table 5).

Table 5

<table>
<thead>
<tr>
<th>Family</th>
<th>Rank</th>
<th>Total landings 1950-2011 (Mt)</th>
<th>Percentage of total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clupeidae</td>
<td>1</td>
<td>514.0</td>
<td>46.1</td>
</tr>
<tr>
<td>Engraulidae</td>
<td>2</td>
<td>423.7</td>
<td>38.0</td>
</tr>
<tr>
<td>Osmeridae</td>
<td>3</td>
<td>71.4</td>
<td>6.4</td>
</tr>
<tr>
<td>Ammodytidae</td>
<td>4</td>
<td>38.6</td>
<td>3.5</td>
</tr>
<tr>
<td>Carangidae</td>
<td>5</td>
<td>26.2</td>
<td>2.4</td>
</tr>
<tr>
<td>Scombridae</td>
<td>6</td>
<td>20.5</td>
<td>1.8</td>
</tr>
<tr>
<td>Euphausiidae</td>
<td>7</td>
<td>7.5</td>
<td>0.7</td>
</tr>
<tr>
<td>Dussumieridae</td>
<td>8</td>
<td>6.9</td>
<td>0.6</td>
</tr>
<tr>
<td>Exocoetidae</td>
<td>9</td>
<td>3.3</td>
<td>0.3</td>
</tr>
<tr>
<td>Hemiramphidae</td>
<td>10</td>
<td>1.8</td>
<td>0.2</td>
</tr>
<tr>
<td>Pristigasterida</td>
<td>11</td>
<td>0.4</td>
<td>&lt;0.1</td>
</tr>
<tr>
<td>Hyptychidae</td>
<td>12</td>
<td>0.3</td>
<td>&lt;0.1</td>
</tr>
<tr>
<td>Atherinidae</td>
<td>13</td>
<td>&lt;0.01</td>
<td>&lt;0.1</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td><strong>1,114.6</strong></td>
<td></td>
</tr>
</tbody>
</table>

Figure 1: Global SPF landings by taxonomic family – 1950 - 2011

As mentioned above, the major contributor to global landings of SPF have been members of the family Clupeidae (Table 5). The clupeid landings data are shown in Figure (2) and three major periods can be identified. At the start of the time-series in 1950-1970 Atlantic herring
(C. harengus) was the single most important species contributing around half the total clupeid SPF landings. Herring landings peaked in 1966 at around 4 Mt but then declined strongly. However, this decline was compensated at a global level by a rapid increase in landings of Sardinops sagax (Japanese pilchard was previously classified as a separate species Sardinops melanostictus but it is now thought to be the same species as the S. American pilchard, S. sagax) in both the Pacific Southeast and Northwest which resulted in overall clupeid SPF landings peaking at almost 17 Mt in 1988. The catches of S. American/Japanese pilchard then fell strongly and have been at low levels since 2002. Although landings of herring continued to show recovery during this period, the collapse in landings of S. American pilchard has resulted in overall clupeid landings falling to around 8 Mt in 1993. Since then overall clupeid landings have fluctuated around the 7 to 8 Mt yr\(^{-1}\) level. Over the past two decades there has also been a trend for increased landings of clupeid species which were previously of minor importance e.g. Araucanian herring (Strangomera bentincki). The proportion of landings made up by species in the “Others” category has also increased over time (Figure 2).

Figure 2: Global SPF landings (Clupeidae) 1950 – 2011. Species included in this category are Argentine menhaden, Atlantic thread herring, Bali sardinella, Bloch’s gizzard shad, Bonga shad, Brazilian menhaden, Brazilian sardinella, Chacunda gizzard shad, Dotted gizzard shad, Falkland sprat, Goldstripe sardinella, Japanese sardinella, Madeiran sardinella, Pacific menhaden, Pacific thread herring and Toli shad.

The second major family contributing to global SPF landings are the engraulids (Figure 3). In 1950 landings were low at around 0.5 Mt yr\(^{-1}\) but they began to increase dramatically from 1955. The species behind this increase was the Peruvian anchovy (anchoveta) and catches increased at such a rate that 15 years later engraulid landings peaked at 29 times the 1950 level. However, anchoveta landings are typified by large fluctuations of up to seven-fold over a period of one or two years. It is these large fluctuations in anchoveta catches that drive the patterns in total engraulid landings. From a low in 1983 anchoveta (and thus combined engraulid) catches have recovered and, apart from several low years (1998, 2002, 2004 and 2010), total engraulid landings have been fluctuating around 9 Mt yr\(^{-1}\). As noted earlier it is
the temporal instability in anchoveta (and thus engraulid) landings which largely drive the overall fluctuations seen in global SPF landings (Figure 1).

![Global engraulid SPF landings by species](image)

**Figure 3: Global SPF landings (Engraulidae) by species – 1950 - 2011**

Contributing around 7% of overall SPF landings (Table 5) osmerid catches are dominated by a single species, the capelin (*Mallotus mallotus*). Until 1964 osmerid catches were rather low at less than 0.25 Mt yr\(^{-1}\) but began to increase from 1965 (Table 5). The peak in osmerid landings occurred in 1977 at just over 4 Mt and landings have generally declined since. From 2004 total engraulid landings have been less than 1 Mt yr\(^{-1}\). Catches of other osmerid SPF species tend to be either locally important or small-scale commercial so that their contribution at a global level is negligible (Table 3).
Members of the Ammodytidae are the fourth-most important SPF group in terms of global landings (Table 5). FAO landings for this group are only recorded as either sandeels (Ammodytidae spp.) from the north-eastern Atlantic or Pacific sandlance (*Ammodytes personatus*). The overall pattern is largely driven by catches of sandeels (Figure 5) which have increased steadily since 1955 reaching a peak of about 1.25 Mt in 1997. Landings then declined strongly hitting a low of around 0.2 Mt in 2005. Since then sandeel catches have increased somewhat to around 0.4 Mt. Landings of sandlance from the Pacific have been about half the catches from the NE. Atlantic so that in recent years the total landings have been around 0.6 Mt yr$^{-1}$.
In terms of global SPF landings the fifth most important group are the smaller members from the family Carangidae. Between 1950 and 2011 they have contributed about 2.5% of the total SPF landings (Table 5). This family includes many medium-sized pelagics so the pattern shown in Figure 6 is influenced by the maximum length cut-off used (50 cm). Total landings have never exceeded 1 Mt yr\(^{-1}\) and recently have been less than a 0.5 Mt yr\(^{-1}\). The main contributing species has been the Japanese jack mackerel (*Trachurus japonicus*). Landings of this species have shown two major periods increasing from 1950 to peak in 1960 and 1950 before declining to a low in 1980. Since then landings have increased and since 1995 have fluctuated between 0.2 and 0.4 Mt yr\(^{-1}\). Catches of Cunene horse mackerel (*Trachurus trechae*) and Japanese scad (*Decapturus maruadsi*) have also fluctuated over time whilst Pacific bumper have been significant for only short periods in the time-series. Recently landings of Shortfin scad (*Decapturus macrosoma*) have become more important.
Figure 6: Global SPF landings (Carangidae) by species – 1950 - 2011

Landings of SPF members of the Scombridae are represented in the FAO database by a single species, *Rastrelliger kanagurta* but there are also records for “Indian mackerels”. It is not possible to separate these further since the three species recorded as being fishing targets (*R. kanagurta*, *R. brachysoma* and *R. faughni*) all overlap in their geographical range (Table 2). These records have therefore been combined (Figure 7). Over the whole time-series catches from this group have contributed about 2% of global SPF landings. Following a period of relative stability (1950-1965) landings of Indian mackerels have increased at an almost linear rate and currently comprise around 0.6 Mt yr⁻¹.
Figure 7: Global SPF landings (Scombridae) by species – 1950 - 2011

FAO records for krill landings are represented by two species, *Euphausia superba* from the Southern Ocean and *Meganyctiphanes norvegica* from the NE. Atlantic. Landings of *M. norvegica* are minor only occurring in a few years (2001, 2003 and 2009). This accords with comments in Tarling et al. (2010) that the northern krill fishery has not developed much beyond the early exploratory stage. There are also no landings records for Isada krill (*E. pacificus*) and it is unclear if there is any current fishery for this species.

In contrast, the fishery for *E. superba* which developed in the mid- to late-1970s has continued ever since. Peak landings (>0.45 Mt yr\(^{-1}\)) occurred between 1980 and 1982 but catches then fell to less than 0.1 Mt in 1993. Since then catches have been increasing and are presently just below 0.2 Mt.
Figure 8: Global SPF landings (Euphausiidae) – 1950 - 2011

Catch data for dussumieriid SPF shows a gradual expansion of species exploited over time (Figure 9). Red-eye round herring (*Etrumeus sadina*) dominated in the 1950s but landings began to decline slightly from 1955. From 1950 increasing quantities of firstly rainbow sardine (*Dussumieria acuta*) and then Whitehead’s round herring (*Etrumeus whiteheadi*) were recorded. However, since 1975 catches of all three species appear relatively steady but increasing in recent years.
Exocoetidae are only recorded as either Japanese flying fish (*Cheilopogon agoo*) or “FlyingFishes nei” in the FAO database. As shown in Table 3 at least 9 species of Exocoetidae are taken on at least a small-scale. In addition, the four-wing flying fish (*Hirundichthys affinis*) was not included in Table 3 as its reported trophic level is 3.8 but this species is known to be locally important in the Caribbean. The geographical range of many of these species also overlaps so it is not possible to disaggregate the mixed Flyingfishes category further. Also it should be noted that in 1999 Peru recorded an anomalously high catch of flying-fishes (298,373 tonnes). This figure exceeds by around 7 times any other catch record for this taxa by this country. This record has thus been excluded from Figure 10 but was included in the summary of global total SPF catches (Table 5).

Total reported landings of flyingfishes have increased since 1950 reaching a peak of just under 100,000 tonnes in 1992. Since then there may have been a decline but contributing to this is that fact that reported catches of Japanese flying fish have fallen to zero since 2007. It is unclear if this is genuine or represents a reporting issue but there has not been a concurrent increase in reported catches of FlyingFishes (mixed) by Japan so this cannot be explained as a simple transfer of data between taxa.
The remaining SPF species listed in Tables 1, 2 and 3 belong to the families Hemiramphidae, Pristigasteridae, Hyptychidae and Atherinidae. In terms of volumes landed they represent a minor component (<0.5% of the total global SPF landings between 1950 and 2011). The landings data for these minor species have been plotted in Figure 11.

The combined landings of these species increased steadily from 1950 until 1985 following which there was a period of stability but landings have again increased a little recently. The main driver for this pattern is the catches of halfbeaks. Only Ballyhoo (Hemiramphus brasiliensis) and Japanese halfbeak (Hyporhamphus sajori) landings are recorded to species level, the remainder are grouped as “Halfbeaks nei” which will include non-SPF as well as SPF species (Table 3). Catches of halfbeaks increased almost linearly from 1951 to 1990 after which they have been relatively stable at around 40,000 t yr⁻¹. Across the time-series catches of Korean sandlance (Atherina hepsetus) have fluctuated without an obvious pattern. A zero catch has been reported for 2010 and 2011 for this species but it is unclear if this is reflects the true position (very small catches have also been reported for some other years). Landings of West African ilisha (Ilisha africana) began to be reported in 1968 and have increased steadily reaching just over 23,000 tonnes in 2011. This increase is mainly due to an increasing range of countries reporting data for this species so it is unclear if historically the landings were under-estimated. Landings of Mediterranean sand-smelt (Atherina hepsetus) have only been reported for 2011 and have been so small as to barely register in Figure 11.
2.2. Geographical and national patterns in SPF landings

2.2.1. Patterns within FAO fishing regions

Although SPF can be found across the world’s oceans and at nearly all depths (Section 1), most of the species listed in Tables 1, 2 and 3 are found in the shelf seas (< 200 m depth) or close to the coast. SPF distribution is strongly influenced by patterns in primary and secondary production with the greatest abundances occurring in areas supported by oceanographic upwelling (Bakun 1996). It is thus no coincidence that major SPF fisheries developed in these areas. This pattern of coastal SPF fishing has shifted a little over time as distant water SPF populations have been targeted e.g. Antarctic krill although these still make up a relatively small proportion of total SPF landings.

Data on the total yields of SPF by FAO reporting area between 1950 and 2011 are shown in Table 6 and the time-series in Figures 12, 13 and 14. Many of the areas appear to conform to the classical fisheries development pattern of a rapid initial increase in catches followed by a decline to a new more stable, or re-building period. Catches from some regions also show some evidence of possible cycles although the time-series is still too short to really confirm this (evidence for long-term cycles in SPF populations is discussed later in the report). Three regions seem to be exhibiting continued increases in catches, namely the eastern and western Indian Ocean and the Central Eastern Atlantic. Fisheries for krill in the Indian and Pacific Antarctic sectors began in the mid-1970s but were short lived. In contrast, commercial fishing for krill has continued in the Atlantic Antarctic up to the present-day.
Table 6: Total landings of SPF species by FAO reporting region from 1950-2011

<table>
<thead>
<tr>
<th>Area</th>
<th>Rank</th>
<th>Total landings 1950-2011 (Mt)</th>
<th>General trend</th>
<th>Number of peak periods</th>
<th>Peak years</th>
<th>Recent trend (since 2000)</th>
<th>Yield in 2011 (Mt)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pacific Southeast</td>
<td>1</td>
<td>411.5</td>
<td>Erratic</td>
<td>2</td>
<td>1970, 1994</td>
<td>Declining</td>
<td>9.3</td>
</tr>
<tr>
<td>Atlantic Northeast</td>
<td>2</td>
<td>248.2</td>
<td>Stable with outbursts</td>
<td>3</td>
<td>1966, 1977, 1997</td>
<td>Decline levelling off</td>
<td>3.4</td>
</tr>
<tr>
<td>Pacific Northwest</td>
<td>3</td>
<td>169.7</td>
<td>Increasing with single outburst</td>
<td>1</td>
<td>1988</td>
<td>Declining slightly</td>
<td>2.2</td>
</tr>
<tr>
<td>Atlantic Eastern Central</td>
<td>4</td>
<td>59.3</td>
<td>Increasing</td>
<td>2</td>
<td>1976, 1990</td>
<td>Increasing</td>
<td>1.7</td>
</tr>
<tr>
<td>Atlantic Northwest</td>
<td>5</td>
<td>40.7</td>
<td>Stable with outbursts</td>
<td>3</td>
<td>1962, 1968, 1990</td>
<td>Declining slightly</td>
<td>0.5</td>
</tr>
<tr>
<td>Atlantic Western Central</td>
<td>6</td>
<td>39.7</td>
<td>Dome-shaped</td>
<td>1</td>
<td>1983</td>
<td>Decline levelling off</td>
<td>0.7</td>
</tr>
<tr>
<td>Mediterranean</td>
<td>7</td>
<td>34.1</td>
<td>Increasing with outburst</td>
<td>1</td>
<td>1984</td>
<td>Increasing slightly</td>
<td>0.7</td>
</tr>
<tr>
<td>Pacific Western Central</td>
<td>8</td>
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<td>Sigmoidal</td>
<td>-</td>
<td>-</td>
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<tr>
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<td>9</td>
<td>23.5</td>
<td>Erratic dome-shaped</td>
<td>3</td>
<td>1973, 1978, 1990</td>
<td>Declining slightly</td>
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</tr>
<tr>
<td>Indian Ocean Western</td>
<td>10</td>
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<td>Increasing</td>
<td>-</td>
<td>-</td>
<td>Increasing</td>
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<tr>
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<td>Level then declined</td>
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<td>1981, 2006</td>
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<tr>
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<td>14</td>
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<td>Dome-shaped</td>
<td>1</td>
<td>1973</td>
<td>Increasing</td>
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<tr>
<td>Atlantic Antarctica</td>
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<td>Increasing with outbursts</td>
<td>3</td>
<td>1980, 1982, 1987</td>
<td>Increasing</td>
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</tr>
<tr>
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<td>16</td>
<td>0.8</td>
<td>Single peak</td>
<td>1</td>
<td>1981</td>
<td>Zero catch</td>
<td>-</td>
</tr>
<tr>
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<td>0.04</td>
<td>Single peak</td>
<td>1</td>
<td>1984</td>
<td>Zero catch</td>
<td>-</td>
</tr>
<tr>
<td>Pacific Southwest</td>
<td>18</td>
<td>0.01</td>
<td>Single peak then declined</td>
<td>1</td>
<td>1990</td>
<td>Declining</td>
<td>&lt;0.01</td>
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</tbody>
</table>

Total 1,114.6 100.0
Figure 12
Figure 13: Global SPF landings for top 6 fishing areas
Figure 14: Global SPF landings for bottom six fishing areas

The patterns in landings over time are driven both by the population dynamics of the targeted SPF species (availability) but also by changes in fishing practices and markets. In general the catches from most regions have been dominated by less than five species but in the central Pacific and eastern Indian Oceans the catches have tended to be more diverse.
The first group comprises regions where engraulids make up around half or more of the total landings (Figure 15). This set includes the Pacific Southeast, Mediterranean, Atlantic Southeast and Pacific Eastern Central regions. Engraulid catches from the Pacific Southeast are dominated by anchoveta (Table 7) and volatility in landings of this species largely explains the erratic nature of SPF landings from this region. The remaining species landed, providing just under a quarter of the total, are clupeids, mainly S. American pilchard and Araucanian herring. In the Mediterranean, catches of European anchovy dominated (61%) with European pilchard and European sprat (both clupeids), being next most important (Table 8). In the Atlantic Southeast, South African anchovy was the most important SPF landed with Cunene horse mackerel and Whitehead’s round herring next (Table 8) whilst in the Pacific Eastern Central California anchovy was the most important species (Table 9).

The second group of areas are ones where the catches have been dominated by clupeids (Figure 16). This set includes the Atlantic regions (excepting the Southeast and Antarctica) plus the Western Indian Ocean and the Pacific Northeast and Northwest. In the Pacific Northwest, the main clupeid landed was S. American pilchard and the main engraulid landed the Japanese anchovy (Table 7). Landings from the north-eastern Atlantic (ranked second in terms of total yield) have traditionally been dominated by Atlantic herring although capelin (an osmerid) has at times been more important (Figure 2). Compared with the Pacific Southeast, there was a wider spread of families and species in the catches, with sandeels, European sprat and pilchard being important. Again this wider spread of exploited SPF species may explain the greater stability in catches from this region. Catches from the other high yielding Atlantic regions were even more strongly dominated by clupeids. In the north-western Atlantic (rank 5 overall), herring remained the most important species landed, although yields of menhaden were almost as large (Table 7), whilst in the central Atlantic regions the dominant clupeids in the catches were European pilchard and round sardinella (Eastern Central) and Gulf menhaden and round sardinella (Western Central). In the Western Indian Ocean, the Indian oil sardine and Indian mackerels made up the bulk of the catch while in the north-eastern Pacific nearly all the catch was Pacific herring (Table 8). Landings from the remaining Atlantic region (Southwest) were dominated by the Brazilian sardinella.

The third group comprises regions where the catches come from a mixture of families, or the less dominant families overall (Figure 17). This group includes Pacific Western Central, Indian Ocean Eastern and Pacific Southwest regions. The central western Pacific and eastern Indian Ocean catches are somewhat similar in being dominated by landings of Indian mackerels. In both regions a wide range of other SPF are also important. The Pacific Southwest is the least important area in terms of overall landings which were dominated by species belonging to the Hemiramphidae (half-beaks). Small amount of anchovies were also recorded.

The final group are the Antarctic regions where SPF catches are not plotted because they comprised solely the Antarctic krill, *E. superba.*
Figure 15: Proportions of SPF landings by family in engraulid dominated fishing areas

Figure 16: Proportions of SPF landings by family in clupeid dominated fishing areas
Figure 17: Proportions of SPF landing by family in mixed fishing areas
Table 7: Species composition of SPF landings for top six FAO fishing regions

<table>
<thead>
<tr>
<th>Area/FAO name/Rank</th>
<th>Landings (Kt)</th>
<th>Makeup (%)</th>
<th>Area/FAO name</th>
<th>Landings (Kt)</th>
<th>Makeup (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pacific Southeast (1)</td>
<td></td>
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<td>Atlantic Eastern Central (4)</td>
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<td></td>
</tr>
<tr>
<td>Anchoveta</td>
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<td>31,299</td>
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<tr>
<td>South American pilchard</td>
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<td>Round sardinella</td>
<td>11,641</td>
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</tr>
<tr>
<td>Araucanian herring</td>
<td>12,392</td>
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<td>Bonga shad</td>
<td>6,607</td>
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<tr>
<td>Longnose anchovy</td>
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<td>European anchovy</td>
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</tr>
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<td>Pacific thread herring</td>
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<td>0.2</td>
<td>Madeiran sardinella</td>
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<td>Cunene anchovy</td>
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<td>West African ilisha</td>
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<tr>
<td>Falkland sprat</td>
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<td>Flyingfishes nei</td>
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<td>0.1</td>
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<tr>
<td>Red-eye round herring</td>
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<td>Halfbeaks nei</td>
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<td>&lt;0.1</td>
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</tr>
<tr>
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<td></td>
<td>Atlantic Northwest (5)</td>
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<td>Atlantic herring</td>
<td>19,053</td>
<td>46.8</td>
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<td>Capelin</td>
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<td>Atlantic menhaden</td>
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<td>44.5</td>
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<td>Capelin</td>
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<td>Rainbow smelt</td>
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<td>11,008</td>
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<td>Halfbeaks nei</td>
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<tr>
<td>Rainbow smelt</td>
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<td>&lt;0.1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pacific Northwest (3)</td>
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<td></td>
<td>Atlantic Western Central (6)</td>
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<td></td>
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<td>Gulf menhaden</td>
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<td>Fishingfishes nei</td>
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<td>Anchovies nei</td>
<td>35</td>
<td>0.1</td>
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<tr>
<td>Red-eye round herring</td>
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<td>1.8</td>
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<td>&lt;0.1</td>
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<td></td>
<td></td>
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<tr>
<td>Slender rainbow sardine</td>
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### Table 8: Species composition of SPF landings for middle six FAO fishing regions

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<tr>
<th>Area/FAO name/Rank</th>
<th>Landings (Kt)</th>
<th>Makeup (%)</th>
<th>Area/FAO name/Rank</th>
<th>Landings (Kt)</th>
<th>Makeup (%)</th>
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<tr>
<td><strong>Mediterranean</strong></td>
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<td>Indian mackerels nei</td>
<td>5,657</td>
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<td>2,027</td>
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<td>Flyingfishes nei</td>
<td>34</td>
<td>0.2</td>
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<td>Buccaneer anchovy</td>
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<td>Red-eye round herring</td>
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<td>&lt;0.1</td>
<td>Bloch’s gizzard shad</td>
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<td>&lt;0.1</td>
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<td><strong>Indian Ocean Eastern</strong></td>
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<td>&lt;0.1</td>
<td>Toli Shad</td>
<td>20</td>
<td>0.1</td>
</tr>
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<td><strong>Atlantic Southeast</strong></td>
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<td><strong>Pacific Northeast</strong></td>
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<td>Pacific herring</td>
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<td>Whitehead's round herring</td>
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<td>West African ilisha</td>
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<td></td>
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<tr>
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<td>&lt;1</td>
<td>&lt;0.1</td>
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</table>
During the period 1950 to 2011 the number of nations fishing for SPF in the different regions has changed both as a result of fisheries management and political and market changes. These changes are illustrated in Figures (18, 19 and 20).

The number of nations recording SPF catches from the top yielding region (Pacific Southeast) has stayed relatively constant over time. In 1950 only Peru and Chile reported catches from this region but this changed between 1977 and 1990 (Figure 18). In 1978 the Soviet Union began catching relatively small amounts of S. American pilchard but this ceased in 1988 with the beginning of the break-up of the Soviet state. From this time separate landings were recorded from Estonia, Georgia, Latvia, Lithuania, Poland, the Russian Federation and Ukraine. However, the number of eastern European countries fishing in the region fell sharply between 1990 and 1992. From 1992 onwards the nations reporting SPF catches from this region have included only the original two, plus Ecuador (and a single small catch record for Colombia in 2010).

The number of countries catching SPF in the Atlantic Northeast at the start of the time-series was much higher (17) reflecting the geography of the region (Figure 18). After 1971 numbers increased, to reach a present-day 22. Again part of the reason for the jump in the late 1980s was the collapse of the Soviet Union followed by separate catch records for nations such as Estonia, Latvia, Lithuania and the Russian Federation.

Nations fishing in the Pacific Northwest have only expanded slightly over time from four in 1951 to six in 2011. The present complement includes (in order of 2011 landings) China, Japan, Republic of Korea, Russian Federation, Taiwan (Province of China) with small catches of slender rainbow sardine by the Hong Kong Special Administrative Region.

In contrast to the relative stability of the other top six SPF regions, the number of nations catching from the eastern central Atlantic has increased steadily from eleven in 1950 to thirty-three in 2011 (Figure 18). This region is currently exploited by a wide range of “local” (e.g. Cameroon, Ghana, Senegal and Sierra Leone and Sao Tome and Principe) and distant-water nations from Europe (e.g. Netherland, Norway, Poland, Romania, Russian

### Table 9: Species composition of SPF landings for bottom six FAO fishing regions

<table>
<thead>
<tr>
<th>Area/FAO name/Rank</th>
<th>Landings (Kt)</th>
<th>Makeup (%)</th>
<th>Area/FAO name</th>
<th>Landings (Kt)</th>
<th>Makeup (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pacific Eastern Central (13)</td>
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<td>Atlantic Antarctic (15)</td>
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<td></td>
</tr>
<tr>
<td>California anchovy</td>
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<td>Antarctic krill</td>
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<td>Pacific thread herring</td>
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Federation, Ukraine and the United Kingdom) and beyond (e.g. Belize). Many of these fisheries may be operating under trans-national agreements.

In contrast to patterns shown in the other size top areas the number of nations fishing in the northwest Atlantic has gone through two periods of increase and decrease. In 1950 the only two nations catching SPF in this region were the United States of America and Canada. From 1959 there was a dramatic increase with entrant countries including the Soviet Union, Poland, Germany, Norway, Iceland, Japan, France, Spain, Bulgaria, Romania, Cuba, Greenland and Portugal. By 1981 all these except the Soviets and Greenland had dropped out. There followed another period of increase up to 1990 made up of the Russian Federation, quite a few of the emergent Eastern European states such as Lithuania, Estonia and Latvia but also re-entry by Norway, Japan, Cuba and Portugal. Over the following four years there was another decline so that by 1995 the main countries were back down to the original two, plus very small landings from Greenland and Cuba.

The number of nations fishing the western central Atlantic has also risen moderately since 1950 to reach 13 by 2011. However most of these are landing small amounts of SPF (<100 tonnes). In terms of SPF landings the dominant fishers were from the USA and Venezuela. Much smaller quantities of SPF were landed by South American and Caribbean nations such as Barbados, Dominican Republic, Martinique, Mexico and Saint Lucia. There were no records of SPF landings from this region from distant-water nations.

Figure 18: Number of countries fishing for SPF in the top six yielding fishing areas – 1950 - 2011

Two of the mid-ranking regions have shown strong increases in the number of nations fishing for SPF since 1950, namely the Mediterranean and the western Indian Ocean (Figure 19). Two regions have shown a smaller increase over this time period (Atlantic Southeast and
Pacific Western Central) whilst one has been rather constant (eastern Indian Ocean) and one has decreased (northeast Pacific).

There appears to have been a steady increase up to 1985 in countries reporting SPF catches from the Mediterranean after which the rate of increase picked up. Some of this later increase can be explained by the break-up of Yugoslavia and the emergence of separate records for countries such as Croatia and Montenegro. In 2011 the most important countries in terms of SPF catches from the Mediterranean (and Black Sea) were in descending order Turkey, Italy, Croatia, Ukraine, Algeria, Spain, Georgia, Tunisia, the Russian Federation and Greece, all landing > 15,000 tonnes.

The increase in countries landing from the western Indian Ocean can be partly attributed to the start of records from countries such as Saudi Arabia (1981), Oman (1987) and Iran (1997). Whether changes in SPF landings by these countries represents the development of genuinely new fisheries, or merely reflects changes in reporting is unclear. In 2011 the main nations fishing in this region were India, Yemen, Pakistan, Oman and the Islamic Republic of Iran.

In 1950 there was only one minor record of SPF landings from the Southeast Atlantic from Angola. By 1979 a peak was reached with the main countries including South Africa, the Soviet Union and Angola. There then followed a decrease as the minor countries Iraq, Poland and Germany dropped out, followed by another increase in 1988 (Romania, Russian Federation, Israel and Lithuania entering) and then another decline. In 2011 the main nations fishing in the southeast Atlantic were South Africa and Angola with Namibia recording very small landings.

For the central western Pacific there has been an even slower increase in nations fishing SPF in this region. In 1950 these were Thailand, Indonesia, Malaysia, Singapore and Fiji and by 2011 these had been joined by the Philippines with small catches also being reported by Kiribati.

As seen in Figure 13, landing of SPF from this region have increased strongly since 1950 but the responsible for the catches have not changed since 1950. They are in order of importance (based on 2011 landings) Malaysia, India, Indonesia and Thailand with lesser amounts caught by Australia.

The Pacific Northeast is the only region to show a fall in the number of nations fishing for SPF within it. This is due to Japan dropping from the time-series following the overall decline in landings of Pacific herring from 1963 to 1968. Between 1960 and 1979, the Soviet Union also caught large quantities of Pacific herring from this region.
Among the bottom size SPF ranking regions, the numbers of countries fishing over time fall into two groups. Firstly there are regions where the number of countries has not increased or has increased moderately over time, namely Pacific Southwest and Atlantic Southwest. In the eastern central Pacific there has been a slightly stronger increase (although the total number of nations involved is still much less than in some of the higher yielding regions). The Pacific and Indian Antarctic showed an almost identical rise and fall with currently zero nations catching SPF in their waters. In contrast, there has been a strong increase in nations catching SPF in the Atlantic Antarctic, from zero in 1972 to six in 2011.

Catches from the Pacific Southwest consist of small amounts of landings by Australia and New Zealand. In 1950, only Brazil and Argentina reported SPF landings from the southwestern Atlantic. In 1990 this had increased to seven nations including the Russian Federation, Latvia, Lithuania and Estonia, although Brazil and Argentina still dominated the landings by orders of magnitude. By 2011, this had fallen to the two main countries plus very small landings from Uruguay and the Falkland Islands (Malvinas).

Nations reporting SPF catches from the eastern central Pacific have increased from one (United States of America) to five now led by Mexico and Panama with the United States third. Very small quantities of catch are reported by the Cook Islands and French Polynesia.

The development of the Antarctic krill fisheries has already been described briefly (Figure 14). In the Indian Antarctic the number of nations taking part peaked around 1979 and included Japan, the Soviet Union, Republic of Korea and France (reporting a very small catch of 6 tonnes) while in the Pacific only Japan and the Soviet Union were involved. By 1997 fishing for krill in these two regions had ceased. In contrast in the Atlantic Antarctic area the number of nations involved has continued to increase so that in 2011 it included Norway, Republic of Korea, Japan, China, Poland and Chile. In 2004 the most nations were
involved including Vanuatu (with nearly 30,000 tonnes) – since this island state lies in the Pacific this seems to be an issue of vessel registration. Ukraine, United States of America, Russian Federation and the United Kingdom also took catches of krill in that year.

Figure 20: Number of countries fishing for SPF in the bottom six yielding fishing areas

In summary most FAO fishing regions show an increasing number of countries reporting SPF landings over time. In some cases the increases in the number of nations involved are quite moderate but in others, such as the central eastern Atlantic, a three-fold increase has occurred. In some areas, such as the central eastern Pacific, the rate of increase has levelled off in recent years whilst in others it is still increasing e.g. the Mediterranean. A few areas have shown temporary jumps in the number of nations involved e.g. the Atlantic Northwest. In the Antarctic sectors of the Indian and Pacific Oceans this pattern represents exploratory fisheries for krill which failed to develop further.

Whether increases in the numbers of countries fishing for SPF in each region always represents a true increase in the number of countries involved is unclear as many nations have improved their reporting since 1950. Early records therefore probably under-report the number of countries involved at the time. Also reporting of small amounts of catch may be erratic contributing to some of the noise in the time-series. As discussed above some of the increases in the mid- to late 1980s can be attributed to the fragmentation of large political entities such as the Soviet Union and Yugoslavia, but these can be identified by careful examination of the time-series.
2.2.2. National SPF fishing patterns

Between 1950 and 2011, 124 nations have reported SPF landings to the FAO database (Table 10). Changes in landings by the top ten countries over time are shown in Figure 21 and patterns in the species composition of landings of the top five are examined in more detail below.

Figure 21: Reported global SPF landings by the top ten countries – 1950 - 2011

In terms of volumes of SPF landed since 1950, Peru tops the ranking having caught nearly 320 Mt, around 86% of which was anchoveta as well as S. American pilchard (41.9 Mt), Longnose anchovy (1.3 Mt), Pacific menhaden (0.6 Mt) and Flying fishes (0.5 Mt). However, it is the strong variation in anchoveta catches which really dominate short-term fluctuations in both Peruvian and total global SPF landings (Figures 1, 21 and 24).
Japan was ranked second overall landing 113.6 Mt of SPF, the majority of which was Japanese pilchard (62 Mt) plus 19 Mt of Japanese anchovy (Figure 23). Japanese SPF landings over the period 1950-2011 were characterized by the wide range of species landed which included Japanese jack mackerel, *Trachurus japonicus* (14.5 Mt), Pacific sand lance *Ammodytes personatus* (6.7 Mt), Japanese scad *Decapterus maruadsi* (3.1 Mt), red-eye round herring *Etrumeus sadina* and Pacific herring *Clupea pallasi* (both 2.7 Mt). Other less important species include Japanese flyingfish *Cheilopogon agoo*, dotted gizzard shad *Konosirus punctatus*, capelin *Mallotus villosus* and Atlantic herring *Clupea harengus*. Small quantities of Indian mackerels, Cunene horse mackerel *Trachurus trechae* and mixed Flyingfishes are also recorded. The total landings of these minor species were 823 Kt. Japan has also landed significant quantities of Antarctic krill since the mid-1970s (1.7 Mt) representing around 23% of the total global catch of *E. superba* over this time-period. There have been three main phases for the most important species - Japanese pilchard and Japanese anchovy. Up to 1972, anchovy and jack mackerel contributed the bulk of the catches but there was then a remarkable increase in Japanese pilchard. This resulted in a peak in landings of over 5 Mt in 1988. However, catches of pilchard then decreased as rapidly and have been minimal since 2002. After this decline, the contribution of Japanese jack mackerel remained relatively small but landings of Japanese anchovy increased slightly. Pacific herring was an important component of Japanese landings at the start of the time series but catches decreased until it became virtually absent in the landings records after 1992. There was a build-up in catches of Antarctic krill between 1979 and 1983 but since 1996, Japan has recorded zero catches for *E. superba*. 
Figure 23: Reported SPF landings by Japan – 1950 -2011

Chile has third-rank overall (Figure 24) and, like Peru, has landed considerable quantities of anchoveta (45 Mt) and S. American pilchard (29 Mt). However, Chile has also landed a range of other SPF species including Araucanian herring (12 Mt), Pacific menhaden (0.25 Mt), Falkland sprat (0.23 Mt) and Antarctic krill (50,000 t). Over time the relative proportions of the main species landed (anchoveta and pilchard) have been very similar to Peruvian catches. Anchoveta was relatively less heavily exploited by Chile in the period 1955 to 1975 but the same pattern of increase in landings of S. American pilchard is observed at the time when the anchoveta stocks crashed. Since 1988, Araucanian herring landings have also increased steadily reaching around 0.89 Mt in 2011. Catches of Pacific menhaden increased slightly from 2000 whilst Falkland sprat has only been landed from 2005 onwards. The amount of E. superba harvested by Chile represents about 0.7% of the total krill landings by all countries.
From 1950 to 1965 SPF species caught by Norway (ranked fourth) were dominated by Atlantic herring (Figure 25). After 1965 the importance of herring declined being largely replaced by catches of capelin. Around 1985 landings of capelin declined sharply and over the next decade landings of herring increased once more. Over the whole time-series Norway has landed around 35 Mt of Atlantic herring and 30 Mt of capelin. Norwegian fisheries also exploit a range of other SPF including NE. Atlantic sandeels (4.4 Mt) and European sprat (1.4 Mt). Small amounts of European pilchard (0.02 Mt) and European anchovy (136 t) have also been landed. A Norwegian fishery for Antarctic krill emerged from 2006 which has landed a total of 0.38 Mt (around 5% of the total E. superba landings by all countries). A small experimental fishery for Norwegian krill also took place in 2009 but only landed 40 t.
**Table 10: National ranking in terms of total SPF reported landings during period 1950 to 2011**

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<th>Rank</th>
<th>Country</th>
<th>Landings (tonnes)</th>
<th>Rank</th>
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<td>Channel Islands</td>
<td>718</td>
<td>113</td>
<td>New Zealand</td>
<td>596</td>
<td>114</td>
<td>Montenegro</td>
<td>504</td>
</tr>
<tr>
<td>115</td>
<td>Puerto Rico</td>
<td>334</td>
<td>116</td>
<td>St. Pierre and Miquelon</td>
<td>246</td>
<td>117</td>
<td>Brunei Darussalam</td>
<td>194</td>
</tr>
<tr>
<td>118</td>
<td>Falkland Is.(Malvinas)</td>
<td>158</td>
<td>119</td>
<td>Colombia</td>
<td>153</td>
<td>120</td>
<td>Nicaragua</td>
<td>148</td>
</tr>
<tr>
<td>121</td>
<td>Malta</td>
<td>22</td>
<td>122</td>
<td>Honduras</td>
<td>13</td>
<td>123</td>
<td>Palau</td>
<td>5</td>
</tr>
<tr>
<td>124</td>
<td>US Virgin Islands</td>
<td>4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Total</td>
<td>1,114,738,279</td>
</tr>
</tbody>
</table>
The main SPF species landed by the United States of America were the Gulf and Atlantic menhaden, approximately 33 Mt and 20 Mt being caught respectively between 1950 and 2011. Other significant species include the Atlantic herring (3.6 Mt), Pacific herring (1.7 Mt) and Californian anchovy (1.5 Mt). Less important species include Atlantic thread herring (*Opithonema oglinum*), Round sardinella (*Sardinella aurita*), Eulachon (*Thaleichthys pacificus*), Ballyhoo halfbeak (*Hemiramphus brasiliensis*), Sandeels (Ammodytidae sp.) and red-eye round herring (*Etrumeus sadina*). The combined landings for these minor species across the time-series total around 280 Kt. Catches for most SPF species by the U.S.A. have been relatively stable over time although Atlantic thread herring, which was important up until 1983 are now being landed at a low level (Figure 26).
A few comments should be made about some of the other top ten nations. Before the collapse of the Soviet Union in the early 1990s, the USSR conducted important fisheries for SPF. Soviet fishing was global in scope and a wide range of SPF species were caught including Antarctic krill. Denmark, Iceland, India and China make up the remaining top-ten SPF nations. Some of these nations target a limited range of species, for example 53% of Denmark’s total SPF landings (1950-2011) have comprised of sandeel (Atlantic herring and European sprat were also important). Others, such as India, land a much wider range of species and have significant subsistence and small-scale fisheries although the overall catch is still dominated by a single species, the Indian oil sardine *Sardinella longiceps* (48% of total Indian reported SPF landings). The combined SPF catch by all other non-top-ten nations has also increased since the 1950s to a present day level of around 6.5 Mt (Figure 21).
3. Small pelagic fishes in an ecosystem context

3.1. SPF diets and feeding strategies

For the purposes of this report SPF were defined as having trophic levels of $< 3.5$ so that by definition their diet consists mainly of organisms low in the food-web. Typically this will include phytoplankton and zooplankton but also elements of the microbial community. There has been considerable focus on the early life ecology of many SPF species (Hunter 1976, Blaxter and Hunter 1982) which has contributed to the formulation and exploration of some of the classic fisheries recruitment hypotheses e.g. the critical period hypothesis (herring among others) (Hjort 1914, Hjort 1926); stable ocean hypothesis (northern anchovy) (Lasker 1981), optimal environment window (anchovies and sardines) (Cury and Roy 1989) and the member/vagrant hypothesis (herring - not strictly concerned with recruitment per se but with explaining why there are so many races of herring with discrete spawning grounds and times) (Iles and Sinclair 1982). Very readable accounts of these ideas can be found in Bakun (1996) and Houde (2008).

Marine fish tend to hatch at a relatively size (typically with body lengths of a few mm). In immediate post-hatch larvae the mouth is often closed, the gut rudimentary and a yolk-sac provides nutritional reserves (Nair 1973, O’Connell 1981). However, after exhaustion of the yolk-sac the larvae must begin feeding or otherwise reach a point-of-no return (PNR) from which they will not recover (Blaxter and Ehrlich 1973, Houde and Schekter 1980). The time taken to reach PNR varies with species, larval size and the amount of yolk reserves and is also negatively related to water temperature (Meyer et al. 2012). In temperate waters the yolk-sac can persist for up to a week but in warmer waters the yolk-sac can be exhausted in as little as two days (Nair 1973). Before the PNR, starvation can also affect predator avoidance behaviour potentially leading to increased mortality (Blaxter and Ehrlich 1973, Skajaa et al. 2004). Much of the work on the development of feeding by young fish larvae has been undertaken using clupeids, particularly herring (Blaxter and Hunter 1982, Batty 1987). Experiments by Rosenthal and Hempel (1968, 1971), Batty (1987), Blaxter (1968) and Blaxter and Ehrlich (1973) established the minimum food requirements, the visual perception, search patterns and water volumes which larvae could search. These data subsequently contributed to the development of increasingly sophisticated models of fish larval feeding and growth (Vlymen 1977, Beyer 1980, Beyer and Laurence 1981, Pitchford and Brindley 2001, Hufnagl and Peck 2011). One particular problem was that early experiments suggested that a rather high concentration of copepod nauplii would be required by herring larvae, around 4 to 8 nauplii l$^{-1}$ at the time of first feeding falling to about half this level after one month (Rosenthal and Hempel 1971). In experimental rearing it was not unusual to use much higher concentrations, up to 120 nauplii l$^{-1}$ (Werner and Blaxter 1981, Kiørboe et al. 1985) whilst good growth and survival was only achieved by Werner and Blaxter (1981) with concentrations of brine shrimp ($Artemia$) nauplii above 1,300 l$^{-1}$. These estimates seemed high compared with field measurements which were typically around 0.5 to 80 nauplii l$^{-1}$ (Bjørke 1971, Kiørboe et al. 1985). This discrepancy created much debate as it suggested that mass starvation of first-feeding larvae in the sea might be common, a conclusion in line with the original idea of Johan Hjort which had become known as the
“critical period hypothesis” (Hjort 1914, Houde and Schekter 1980, Houde 2008). Similar findings seemed to emerge from rearing experiments with northern anchovy (E. mordax) larvae (Hunter 1976, Schmitt 1986). Eventually several factors emerged which at least partially resolved the discrepancy. Firstly, laboratory rearing tanks rarely duplicate field conditions where wind- and tide-induced turbulence can increase encounter rates between fish larvae and their prey (Rothschild and Osborn 1988, Muelbert et al. 1994, Kiørboe and Saiz 1995, Sundby 1996) (MacKenzie and Kiørboe 1995, Sundby 1995, Fox et al. 1999); secondly certain strains of Artemia have low levels of (n-3) PUFAs and are nutritionally deficient for rearing marine fish. This was not appreciated at the time as illustrated in a review on laboratory rearing of marine larvae in which May (1970) suggested that problems of low larval survival were related to the digestive ability of the larvae, rather than the nutritional adequacy of the prey. Nowadays brine shrimp nauplii are usually enriched using oil emulsions to boost their EFA content before they are added to rearing tanks (Sorgeloos et al. 2001) but at the time of Werner and Blaxter’s experiments the nutritional deficiencies of Artemia were only just beginning to be appreciated (Watanabe et al. 1980, Watanabe et al. 1983). As well as eventually leading to high mortality rates, dietary fatty acid deficiency causes more subtle effects in larval SPF. Herring larvae are visual hunters and dietary deficiency of (n-3)PUFA leads to changes in neural tissue FA-content, reduced visual acuity and impairment of feeding performance at low light levels (Navarro et al. 1993, Bell et al. 1995). Even after enrichment it is the author’s experience that survival rates of herring larvae are substantially higher when reared on natural zooplankton (Fox et al. 2003). Because of these problems with the use of Artemia, as well as issues of availability and cost, there has been growing interest in the use of copepods in aquaculture for larval fish rearing although mass cultivation remains difficult (Ajiboye et al. 2011); thirdly, many published field estimates of the concentrations of copepod nauplii, early copepodite stages and smaller copepod species are probably too low due to sampling with plankton nets with typical mesh-sizes of around 270 µm. A considerable portion of the smaller zooplankton will escape through meshes of this size (Turner 2004, Pitois and Fox 2006). In addition, natural zooplankton is notoriously patchy and large-volume samplers tend to disrupt patches resulting in lower, average concentrations (Young et al. 2009). Several studies have attempted to quantify the levels of starvation or poor growth in the wild using histological or biochemical condition indices (O’Connell 1980, Chícharo et al. 1998, Baumann et al. 2007, Lee et al. 2007). However, larvae which are feeding poorly are probably at enhanced risk of predation so it is difficult to separate the effects of starvation and predation. The extent to which first-feeding represents a survival bottle-neck is also still not resolved (Polte et al. 2013) although attention has tended to move away from tests of the critical period hypothesis to better understanding the controls on growth and survival of fish throughout their pre-recruit stages (Houde 2008).

Many of these have examined how both prey availability and environmental conditions affect feeding success. However, many SPF larvae have straight guts, at least in the earlier stages of development (O’Connell 1981, Blaxter and Hunter 1982), making the contents easy to void under stress. This often results in a large proportion of larvae sampled at sea being empty (Ciechomski 1966, Loukashkin 1970, Islam and Tanaka 2009).

There has also been debate over the degree to which ingestion of phytoplankton (Reitan et al. 1997), bacteria (Bakke et al. 2013) and protists is nutritionally beneficial (Friedland et al. 1984, de Figueiredo et al. 2005, de Figueiredo et al. 2007). These prey may just be ingested accidentally (Parr 1930), either whilst learning to feed (Overon et al. 2010) or through drinking (Fox et al. 1990, Tytler and Ireland 1994). For some species ingestion of pelagic microbes appears to help “prime” first-feeding capabilities but the amount of nutrition actually derived from these sources may be rather limited (Overon et al. 2010). However, this probably does not apply to all SPF species since, in both the field and laboratory, young Gulf menhaden (B. patronus) actively select dinoflagellates and tintinids above copepod nauplii (Stoecker and Govoni 1984). However, copepods do enter the diet as the larvae grow (June and Carlson 1971, Chen et al. 1992). The role of detritus in diet of older Gulf menhaden has been debated but isotope data indicate that juveniles do obtain around 30% of their energy from plant detritus. Their guts also contain cellulase producing microflora allowing them to digest plants such as Spartina (Lewis and Peters 1984, Deegan et al. 1990).

A wealth of data show that phytoplankton and small zooplankton are the preferred prey of SPF larvae (Bainbridge and Forsyth 1971, Bjørke 1971, Rudakova 1971, Houde and Schekter 1980, Houde and Lovda 1984, Stoecker and Govoni 1984, Voss et al. 2009). As the larvae develop the size and range of prey changes gradually moving towards the adult pattern (Friedland et al. 1984, Stoecker and Govoni 1984, Fox et al. 1999, Morote et al. 2008, Morote et al. 2010). For example, Gning et al. (2008) examined feeding of Bonga shad (Ethmalosa fimbriata) in the Sine-Saloum estuary (Senegal) where young juveniles fed on zooplankton (mainly copepods) but at around 30 mm began to include benthic invertebrates from adjacent mangroves. Larger fish (> 51 mm) had increasing amounts of plant material in the diet. Very young European sprat (Sprattus sprattus) often contain green remains, presumably of phytoplankton (Lebour 1918) whilst older larvae prefer the nauplii and copepodites of copepods such as Paracalanus, Pseudocalanus, Acartia and Oithona (Coombs et al. 1992). From the Dussumeriidae, Chen et al. (1992) examined the stomach contents of larval round herring (Etrumeus terrestris) captured in the northern Gulf of Mexico. The diet was rather mixed and included diatoms, tinitinnids, pteropods, pelecypods, copepods (all stages) and invertebrate eggs. The diet of larval engraulids has also been widely examined (Ciechomski 1966, Vinas and Ramirez 1996, Conway et al. 1998, Chesney 2008, Islam and Tanaka 2009, Morote et al. 2010). Larval anchovy generally contained copepods whilst in juveniles a wider range of organisms was taken including calanoid, harpacticoid and cyclopoid copepods, fish eggs and larvae and phytoplankton. In small anchoveta (E. ringens) larvae collected off Peru the gut contents included a range of phytoplankton (diatoms and
dinoflagellates), ciliates, copepod eggs and nauplii. In larger larvae (> 11 mm length) phytoplankton were no longer taken and the gut contents consisted of copepods (all development stages), invertebrate eggs and miscellaneous crustacean. There was also a linear relationship between the width of the larval mouth and width of prey items (Mendiola 1974). Both that paper and Berner (1959) commented on the high percentage of larvae with empty guts but as mentioned previously this could be due to voiding of gut contents on capture. From the Perciformes, Lebour (1918) recorded that young lesser sandeel (Ammodites tobianus) often contained unidentifiable green food remains and that the presence of copepods in the guts of the sandeels at this stage was unusual. The transition from at least some phytoplankton ingestion by small sandeel larvae to a diet principally composed of copepods appears typical and is also seen in American sand-lance, Ammodites americanus (Monteleone and Peterson 1986). Ammodites larvae collected off Greenland consumed mainly copepods although larger sandeel larvae also contained the eggs of copepods and euphausiids as well as bivalve and gastropod larvae (Simonsen et al. 2006).

In many SPF, the transition to an adult diet is accompanied by the development of gill rakers and epibranchial organs and a change of feeding mode (Blaxter and Hunter 1982, Bornbusch and Lee 1992). The Indian oil sardine (S. longiceps), for example, shows a progressive decline in the proportion of crustacea in the diet with the change from juvenile to adult. The gill rakers in the adults are broader, longer and sturdier than in the juveniles and the papillae overlap forming a close mesh (Bensham 1964). In Atlantic menhaden (B. tyrannus) the larvae are particulate feeders selecting mainly copepods but the diet changes to include more phytoplankton as the fish approach metamorphosis. Development of the gill rakers during this transition allows the older fish to feed by filtering (June and Carlson 1971, Friedland 1985). Menhaden switch from selecting phytoplankton at first feeding (Chen et al. 1992) to a larval diet dominated by crustacea then switch back again to a more phytoplankton dominated diet after metamorphosis. In northern anchovy (E. mordax) differentiation of the stomach and pylorus commences when larvae are around 20 mm, by 30 mm the upper and lower jaws and branchial elements attain mobility in preparation for filter feeding and during this period the gill rakers develop and branchial arches lengthen. Metamorphosis occurs around 35 mm. Differences in the morphology of the gill rakers and associated structures, often explain dietary separation when comparing sympatric SPF species (Berry and Barrett 1963, Molina and Manrique 1997). For example, adult Argentine anchovy (E. anchoita) and Peruvian anchoveta (E. ringens) are mainly filter feeders but the diet of the Peruvian anchoveta includes more phytoplankton (Ciechomski and Capezzani 1973). The gill rakers of the Peruvian anchoveta are longer and more numerous and this allows them to filter out smaller particles (Blaxter and Hunter 1982). Similar resource partitioning has been reported in the sympatric Gulf menhaden (B. patronus) and Finescale menhaden (B. gunteri). Phytoplankton are more important in the diet of Gulf menhaden which has longer intermediate gill rakers and higher numbers of branchiospicules thus forming a finer mesh which can entrap smaller particles (Castillo-Rivera et al. 1996).

A summary of some of the available diet information for post-larval SPF is given in Table 11. There is a vast literature on this subject and there is no claim that the references
cited present a definitive view although it is clear that the diets of some groups have been much more intensively studied than others. The examples given are intended to allow the reader an overview of the prey found in SPF stomachs. The available data demonstrate the wide range of plankton consumed by SPF but analysis of stomach contents alone cannot determine if fish are feeding selectively, for that it is necessary to compare the diet with the available prey field (Fox et al. 1999, Casini et al. 2004, Tanaka et al. 2006). Selective feeding has also been studied in the laboratory but with relatively few SPF species (Checkley Jr. 1982, Ohman 1984, Haberman et al. 2003b). James (1988) reviewed clupeid feeding modes and suggested they fall into three groups: (1) predominantly particulate feeders e.g. C. harengus and E. whiteheadii; (2) intermediate (mixed) feeders e.g. Sardinellas and Engraulids and (3) true filter-feeders e.g. C. mysticetus and B. tyrannus. However, feeding modes can be flexible in both groups 1 and 2 as both herring (C. harengus), anchovies (E. capensis, E. mordax) and sardines (S. pilchardus, S. sagax) have been shown to switch between particulate and filter feeding modes depending on conditions (Leong and O’Connell 1969, Blaxter and Hunter 1982, Batty et al. 1986, James 1987, Gibson and Ezzi 1992, Van Der Lingen 1994, Garrido et al. 2007). The relative efficiency of the different feeding modes varies between species, for example sardines are better suited morphologically to capturing smaller particles by filtration compared to anchovies. Furthermore, James & Probyn (1989) showed that in the S. African anchovy, E. capensis, particulate feeding is more energetically efficient. This helps explain why particulate feeding is the preferred feeding mode in this species (James and Findlay 1989). Behaviour also changed when larger prey were introduced so that the school became less tightly packed – again this behaviour was suggested to maximise prey consumption by reducing competition between individual fish (James and Findlay 1989). Feeding mode can also change during the day. During day (or moonlit nights) New Zealand garfish (Hyporhamphus ihi) hunt visually taking copepods and insects trapped at the water surface but during darkness they move deeper into the water column detecting zooplankton prey using their anterior lateral lines (Montgomery and Saunders 1985, Saunders and Montgomery 1985). Most SPF seem to be somewhat generalist planktivores with the diet varying with location and time of year. In some groups, for example the flying fishes, there is a degree of specialisation which may allow resource partitioning (van Noord et al. 2013). Less usual prey, such as salps, may also be exploited at times when preferred prey are unavailable (Mianzan et al. 2001). The extent to which some SPF undertake benthic feeding has been debated but while stomach contents of some species suggest that this does occur, particularly in inshore areas (Vega-Cendejas et al. 1994), the sampling technique can also affect the results.

The idea that the anchovies (E. ringens and C. mysticetus), menhadens (Brevoortia spp.), West African bonga (E. jimbiiruta), Indo-Pacific thread herring (Opisthotorieria libertate), Indian oil-sardine (Sardinella longiceps) and Antarctic krill (Euphausia superba) are all essentially phyto-planktivorous has been a prevalent idea used to explain their high productivity as a result of feeding close to the base of the food-web (Ryther 1969, Longhurst 1971). However, we now know that this concept is only partially correct (Monteiro et al. 1991). Despite diatoms making up more than 99% (by count) of the prey ingested by Peruvian anchovy (E. ringens), this component appears to provide <2% of dietary carbon, the
relatively smaller quantities of more voluminous crustacea ingested actually contributing the bulk of dietary energy (Espinoza and Bertrand 2008, Espinoza et al. 2009). When prey composition is reported by count, the presence of many small items can skew perception of which prey are actually most important. This issue has often been addressed by reporting prey by volume or weight but this only partially addresses the problem. As Espinoza and Bertrand (2008) have illustrated, studies on fish stomach contents which do not consider the relative nutritional value of the different items may be mis-leading (James 1988, Elliott et al. 2007). A similar re-appraisal of the relative importance of autotrophic : heterotrophic energy sources for Antarctic krill (E. superba) has also evolved over time (Schmidt et al. 2006). An additional problem is that the results of stomach content analysis tend to biased towards prey which have harder parts which are more resistant to digestion (Atkinson and Snýder 1997). Modern biochemical approaches can help with these issues, particularly in identifying macerated stomach contents. For example, Jeffries (1975) used fatty acid profiles of the macerated stomach contents of juvenile Atlantic menhaden to show that they were ingesting plant material. Other researchers have also applied modern molecular methods to identify gut contents of SPF (Martin et al. 2006, Passmore et al. 2006, Schmidt et al. 2006, Cleary et al. 2012, Fox et al. 2012). However, even though a prey may be ingested the fish may not be able to efficiently digest it. Proper quantification of energy sources thus requires detailed understanding of the prey ingested, the nutritional value of the different items and the digestive physiology of the predator (Sargent et al. 1979, Seiderer et al. 1987). Such detailed studies have only been carried out on relatively few SPF species. An example is menhaden (B. tyrannus) which has been shown to be capable of efficiently digesting ingested cellulose (Lewis and Peters 1984). Examination of the digestive capabilities of some other SPF groups, particularly the stomach-less Hemiramphidae, is beginning to show how they cope physiologically with omnivorous diets (Day et al. 2011a, Day et al. 2011b). Analyses of isotope signatures in tissues can also be undertaken and used to estimate which trophic levels SPF are actually gaining their nutrition from (Rau et al. 1983, Boyd et al. 1984, Deegan et al. 1990, Monteiro et al. 1991, Schmidt et al. 2006, Malzahn and Boersma 2009, Botto et al. 2011, Faye et al. 2011). Wider application of the full range of available methods for studying fish diets would be helpful because diet composition is one of the basic data requirements for the construction of food-web models. The majority of these diet data have been based upon visual analysis of stomach contents but, as described above, this assumption can sometimes be mis-leading in terms of real energetic pathways.
Table 11: Diet of some juvenile and adult SPF species inferred from stomach contents or other means – the ordering of the species follows that used in Tables 1-3. The ordering of prey items shows approximate ranking in terms of abundance or weight (where stated) in the diet. Where reference states “cited in” it has not been possible to check the original reference.

<table>
<thead>
<tr>
<th>Species</th>
<th>English name</th>
<th>Location</th>
<th>Diet – stomach contents or other method stated</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anodontostoma chacunda</td>
<td>Chacunda gizzard shad</td>
<td>Johor Strait</td>
<td>Cirripede cyprids, phytoplankton</td>
<td>Hajisamae et al. (2003)</td>
</tr>
<tr>
<td>Brevoortia aurea</td>
<td>Brazilian menhaden</td>
<td>Rio de la Plata</td>
<td>Isotopic signature declines with from juvenile to adult indicating shift in diet to lower trophic level.</td>
<td>Boto et al. (2011)</td>
</tr>
<tr>
<td>Brevoortia gunteri</td>
<td>Finescale menhaden</td>
<td>Pueblo Viejo lagoon</td>
<td>Mainly zooplankton.</td>
<td>Castillo-Rivera et al. (1996)</td>
</tr>
<tr>
<td>Brevoortia patronus</td>
<td>Gulf menhaden</td>
<td>Texas</td>
<td>Plants material only.</td>
<td>Matlock &amp; Garcia (1983)</td>
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<td></td>
<td></td>
<td></td>
<td>Pueblo Viejo lagoon</td>
<td>Mainly phytoplankton.</td>
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<td></td>
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<td></td>
<td>Fourleague Bay, Louisiana</td>
<td>Fish tissue isotope signatures indicated ratio of about 30% detritus and 70% plankton in the diet.</td>
</tr>
<tr>
<td>Brevoortia pectinata</td>
<td>Argentine menhaden</td>
<td>Patos lagoon</td>
<td>Isotope signature indicates feeding from low trophic levels.</td>
<td>Garcia et al. (2007)</td>
</tr>
<tr>
<td>Brevoortia tyrannus</td>
<td>Atlantic menhaden</td>
<td>North Carolina</td>
<td>Stomachs contained more amorphous matter in fish sampled from estuaries cf. fish sampled offshore, amorphous material has vascular plant origin.</td>
<td>Lewis &amp; Peters (1994)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>NW Atlantic</td>
<td>By weight: Calanoid copepods, mysids, decapod larvae.</td>
</tr>
<tr>
<td>Clupea harengus</td>
<td>Atlantic herring</td>
<td>West Scotland</td>
<td>Older fish: cladocera, copepods, amphipods, crustacean larvae, sandeels and small gadoids.</td>
<td>de Silva (1973)</td>
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<td></td>
<td></td>
<td></td>
<td>S. North Sea</td>
<td>Fish eggs.</td>
</tr>
<tr>
<td>Species</td>
<td>English name</td>
<td>Location</td>
<td>Diet – stomach contents or other method stated</td>
<td>Reference</td>
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<tr>
<td><em>Clupea harengus</em> con/td</td>
<td>Atlantic herring</td>
<td>North Sea</td>
<td>Age 2 and 3 herring: diet includes plaice (<em>Pleuronectes platessa</em>) and cod (<em>Gadus morhua</em>) eggs, older herring take more euphausiids.</td>
<td>Daan et al. (1985)</td>
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<td></td>
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<td></td>
<td>S. North Sea</td>
<td>Diet broadens as juvenile herring grow to include mysids and post-larval sprat.</td>
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<td></td>
<td></td>
<td>N. Baltic</td>
<td>Copepods and cladocera, larger and more visible prey actively selected.</td>
<td>Flinkman et al. (1992)</td>
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<td></td>
<td></td>
<td>Barents Sea</td>
<td>Juveniles: Mainly copepods but increasing amounts of euphasiids and appendicularia in larger herring</td>
<td>Huse et al. (1996)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>NW Atlantic</td>
<td>By weight: Crustacea, euphausiids (<em>M. norvegica</em>), amphipods, decapod larvae.</td>
<td>Bowman et al. (2000)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>S. Norway</td>
<td>Herring may cannibalise eggs towards end of spawning season</td>
<td>(Skaret et al. 2002)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>S. Baltic</td>
<td>Small herring are zooplanktivorous but larger herring become nektobenthic: mysids (<em>Mysis mixta</em>), amphipods and polychaetes.</td>
<td>Casini et al. (2004)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>S. North Sea</td>
<td>Herring forage on fish eggs when other prey are scarce</td>
<td>(Segers et al. 2007)</td>
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<td></td>
<td></td>
<td>Irish Sea</td>
<td>Plaice (<em>P. platessa</em>) egg remains enumerated in herring stomachs and plaice DNA detected in herring stomachs collected from a plaice spawning ground.</td>
<td>Ellis &amp; Nash (1997), Fox et al. (2012)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>S. Baltic</td>
<td>Crustacea; mainly cladocera (<em>Bosmina coregoni</em>), copepods (<em>Pseudocalanus, Temora &amp; Acartia</em> spp.). Compared with 1950s, mysids in diet now replaced by amphipoda.</td>
<td>Dziaduch (2011)</td>
</tr>
<tr>
<td>Species</td>
<td>English name</td>
<td>Location</td>
<td>Diet – stomach contents or other method stated</td>
<td>Reference</td>
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<tr>
<td><em>Clupea pallasi</em></td>
<td>Pacific herring</td>
<td>Canada</td>
<td>Copepods, euphausiids, amphipods, cladocera; Adults take more fish, polychaetes and larval clams</td>
<td>Hart (1973)</td>
</tr>
<tr>
<td><em>Escualosa thoracata</em></td>
<td>Kowala coval</td>
<td>Various</td>
<td>Review: Early studies; copepods mainly <em>Paracalanus, Acartia &amp; Oithona</em> spp., also cladocera (<em>Evadne</em> spp.), crab zoea, bivalve larvae and fish eggs; Also phytoplankton. Suggested that this species targets spawning grounds of other fish. Other studies reported main food was ghost shrimp (<em>Lucifer hanseni</em>) and other prawns. Other locations; benthic crustacean and algae mostly undigested. In inshore juveniles; cladocera are favoured prey. Feeding varies seasonally being more intense post-monsoon.</td>
<td>Nair (1973)</td>
</tr>
<tr>
<td><em>Ethmalosa fimbriata</em></td>
<td>Bonga (West African) shad</td>
<td>Sierra Leone River</td>
<td>Adult Bonga: Mainly phytoplankton, some copepod nauplii and copepodites (<em>Paracalanus</em> spp.) and tintinnids. Stomach volume related to amount of phytoplankton available which varied seasonally.</td>
<td>Bainbridge (1957)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Lagos offshore</td>
<td>Mainly detritus, lamellibranch larvae, small copepods</td>
<td>Bainbridge (1957)</td>
</tr>
</tbody>
</table>
|                        |                  | Lagos lagoon    | Bonga < 70 mm long: Copepods, *Acartia & Paracalanus* spp., bivalve & gastropod larvae, larval crabs  
  Bonga 70-169 mm long: Zooplankton, phytoplankton  
  Bonga > 170 mm long: Zooplankton, phytoplankton | Façade & Olaniyan (1972) |
<table>
<thead>
<tr>
<th>Species</th>
<th>English name</th>
<th>Location</th>
<th>Diet – stomach contents or other method stated</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Harengula clupeola</td>
<td>False herring</td>
<td>Virgin Islands</td>
<td>By volume: Copepods (<em>Candacia pachydactyla</em>, <em>Undinula vulgaris</em>), crab and shrimp larvae, polychaetes, pteropods (<em>Creseis</em> spp.), fish eggs</td>
<td>Randall (1967)</td>
</tr>
<tr>
<td>Harengula humeralis</td>
<td>Redear herring</td>
<td>Virgin Islands</td>
<td>By volume: Fishes, polychaetes, shrimp larvae, plants</td>
<td>Randall (1967)</td>
</tr>
<tr>
<td>Harengula jaguana</td>
<td>Scaled herring (sardine)</td>
<td>Yucatan, Mexico</td>
<td>By weight: Fishes (cannibalism), crustaceae (mainly mysids), polychaetes (<em>Nereidae</em>), decapoda larvae</td>
<td>Vega-Cendejas et al. (1994)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Lower Tampa Bay, Florida</td>
<td>By weight: Gastropods, copepods, isopods, cladocera, tunicates, amphipods, bivalves, invertebrate eggs. Significant niche overlap with sympatric <em>A. hepsetus</em></td>
<td>Motta et al. (1995)</td>
</tr>
<tr>
<td>Jenkinsia lamprotaenia</td>
<td>Dwarf round herring</td>
<td>Virgin Islands</td>
<td>By volume: Copepods (<em>Candacia pachydactyla</em>, <em>Corycaeus subulatus</em>, <em>Euchaeta marina</em>, <em>Metis holothurian</em>, <em>Undinula vulgaris</em>), shrimp &amp; crab larvae, amphipods, fish eggs</td>
<td>Randall (1967)</td>
</tr>
<tr>
<td>Opisthonema libertate</td>
<td>Pacific thread herring</td>
<td>Gulf of California</td>
<td>Diatoms (<em>Planktoniella sol</em> &amp; <em>Coscinodiscus</em> spp.), dinoflagellate (<em>Peridinium</em> spp.), also cladocera (<em>Evadne</em>), penaeid prawn larvae and invertebrate eggs, slightly more tendency to select zooplankton cf. diet of <em>S. sagax</em></td>
<td>Molina &amp; Manrique (1997)</td>
</tr>
<tr>
<td>Opisthonema libertate con/td</td>
<td>Pacific thread herring</td>
<td>Gulf of California</td>
<td>Broad range of diatoms, smaller numbers of copepods, (<em>Calanus</em> spp.); able to retain smaller particles cf. <em>E. mordax</em></td>
<td>López-Martínez et al. (1999)</td>
</tr>
<tr>
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<tr>
<td><em>Opisthonema oglinum</em></td>
<td>Atlantic thread herring</td>
<td>Virgin Islands</td>
<td>By volume: Mainly copepods (<em>Candacia pachydaactyla</em>, <em>Oithona</em> spp., <em>Temora stylifera</em>), polychaetes, shrimps and shrimp larvae, fish, crab larvae, mysids, appendicularia, stomatopod larvae, eggs, gastropod larvae, miscellaneous others</td>
<td>Randall (1967)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Yucatan, Mexico</td>
<td>Mainly small benthic crustacea, mollusc larvae, small fish, macrophytes, seagrass, some copepods</td>
<td>Vega-Cendejas et al. (1997)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>NW Spain</td>
<td>C &amp; N isotopes: Zooplankton more important for medium sized sardine, phytoplankton more important to larger sardine but still use a mixed diet.</td>
<td>Bode et al. (2003); Bode (2004)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Izmir Bay, Turkey</td>
<td>Zooplankton, mainly copepods, decapod &amp; bivalve larvae</td>
<td>Sever &amp; Taskavak (2005)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Portugal</td>
<td>Phytoplankton (&lt;20% by vol.); dinophycae &amp; diatoms; zooplankton (&gt;80% vby vol.), tintinnids, forams, crustacea eggs, copepods, cirripede larvae, fish eggs</td>
<td>Cunha et al. (2005)</td>
</tr>
<tr>
<td><em>Sardinella aurita</em></td>
<td>Round sardinella (Spanish sardine)</td>
<td>Senegal</td>
<td>Variable with location and timing; phytoplankton, zooplankton, fish eggs &amp; larvae, detritus taken during non-upwelling periods</td>
<td>Nieland (1982)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>NE Mediterranean</td>
<td>Copepods, amphipods, decapod larvae, less amounts of siphonophores, phytoplankton &amp; fish larvae. Seasonal variability in diet composition</td>
<td>Tsikliras et al. (2005)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Central Mediterranean</td>
<td>Wide variety of planktonic prey. Importantly copepods, euphausiids, amphipods, decapod larvae &amp; siphonophora</td>
<td>Lomiri et al. (2008)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>NW Atlantic</td>
<td>Calanoid copepods</td>
<td>Bowman et al. (2000)</td>
</tr>
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<td>Diet – stomach contents or other method stated</td>
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<tr>
<td><strong>Sardinella albella</strong></td>
<td>White sardinella</td>
<td>Various</td>
<td>Review: Early studies indicated pure planktivory, (<em>Coscinodiscus</em> and <em>Fragilaria</em> spp.); Copepods (<em>Paracalanus</em>, <em>Acartia</em>, <em>Oithona</em>, <em>Corycaeus</em> &amp; <em>Euterpina</em> spp.); Other studies recorded shrimp (<em>Lucifer</em> spp., <em>Acetes</em> and <em>Squilla</em> spp. larvae. Concluded that white sardinella was a selective surface feeder.</td>
<td>Nair (1973)</td>
</tr>
<tr>
<td><strong>Sardinella fimbriata</strong></td>
<td>Fringescale sardinella</td>
<td>Various</td>
<td>Review: Early studies found mostly phytoplankton in guts, some zooplankton, copepods, shrimp (<em>Lucifer</em>), prawns and fish larvae. Later studies found mixed diet, copepods, phytoplankton, more zooplankton in larger fish. Fish larvae at some times of year.</td>
<td>Nair (1973)</td>
</tr>
<tr>
<td><strong>Sardinella gibbosa</strong></td>
<td>Goldstripe sardinella (Indian sprat)</td>
<td>Various</td>
<td>Review: Early studies reported crustacea, mainly brachyuran larvae &amp; copepods; also shrimp (<em>Lucifer</em>), blue-green algae (<em>Trichodesmium</em> spp.) consumed when available, larval bivalves. Larger fish took more phytoplankton, mainly diatoms. Off Waltair, larvae of <em>Acetes</em> and <em>Alpheus</em> spp. common in diet. Evidence of selective feeding.</td>
<td>Nair (1973)</td>
</tr>
<tr>
<td><strong>Sardinella gibbosa con/td</strong></td>
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<td></td>
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<td></td>
<td>W. India Copepods (<em>Oithona</em> spp., <em>Corycaeus giesbrechti</em>, <em>Microstella rosea</em>, <em>Temora stylifera</em>, <em>Euchaeta marina</em>, <em>Corycella</em>, <em>Copilia</em> &amp; <em>Labidocera</em> spp.); shrimp (<em>Lucifer</em> spp.) also important.</td>
<td>Lazarus (1977)</td>
</tr>
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<td></td>
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<td></td>
<td>Kenya Copepods, rotifers, hyperiids, nematodes, brachyuran larvae. Diet varied spatially and seasonally</td>
<td>Nyunja et al. (2002)</td>
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<td></td>
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<td></td>
<td>Kenya Mainly copepods, also phytoplankton, zoobenthos, detritus.</td>
<td>Mavuti et al. (2004)</td>
</tr>
<tr>
<td><strong>Sardinella longiceps</strong></td>
<td>Indian oil sardine</td>
<td>SW India</td>
<td>Juvenile fish take more crustacea, adults more diatoms. Seasonal variability in diet.</td>
<td>Bensham (1964)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Karwar, India Mainly diatoms and copepods, less dinoflagellates, tintinnids, invertebrate larvae &amp; fish eggs</td>
<td>Noble (1969)</td>
</tr>
<tr>
<td>Species</td>
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<tr>
<td>Mangalore</td>
<td></td>
<td>Juvenile oil sardine: By number mainly diatoms, dinoflagellates, fewer copepods except one sample. No obvious relation between diet and fish size</td>
<td>Dhulkhed (1970)</td>
<td></td>
</tr>
<tr>
<td>Various</td>
<td></td>
<td>Review: Early studies thought oil sardine were bottom feeders, later studies suggested it was more a surface feeder on phytoplankton. Zooplankton also taken. Studies on which prey provide most nutrition seem lacking.</td>
<td>Nair (1973)</td>
<td></td>
</tr>
<tr>
<td><em>Sardinella maderensis</em></td>
<td>Madeiran sardinella</td>
<td>Lagos lagoon</td>
<td>Centric diatoms, copepods (<em>Acartia bifilosa</em> &amp; <em>Paracalanus spp.</em>), ostracods, gastropod larvae, bivalves, miscellaneous crustacean</td>
<td>Façade &amp; Olaniyan (1973)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Lagos offshore</td>
<td>Calanoid copepods, amphipoda, isopoda, brachyuran larvae</td>
<td>Marcus (1986)</td>
</tr>
<tr>
<td><em>Sardinops sagax caeruleus</em></td>
<td>S. American pilchard (Pacific sardine)</td>
<td>San Diego</td>
<td>Phytoplankton, crustacean: Diet tends to reflect plankton composition of the water</td>
<td>Lewis (1929)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Central Baja to S. California</td>
<td>Crustacea (89%), small amounts phytoplankton in smaller fish</td>
<td>Hand &amp; Berner (1959)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>California</td>
<td>Similar to <em>E. mordax</em> with which it competes</td>
<td>Baxter (1966)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Gulf of California</td>
<td>Diatoms (<em>Planktoniella sol</em> &amp; <em>Coscinodiscus spp.</em>), dinoflagellate (<em>Peridinium spp.</em>), also cladocera (<em>Evadne</em>), penaeid larvae and invertebrate eggs</td>
<td>Molina &amp; Manrique (1997)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Gulf of California</td>
<td>Copepods (<em>Calanus spp.</em>), brachyuran larvae, diatoms</td>
<td>López-Martínez et al. (1999)</td>
</tr>
<tr>
<td>Species</td>
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<td>Diet – stomach contents or other method stated</td>
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<tr>
<td>S. Benguela</td>
<td></td>
<td>Phytoplankton and zooplankton; Proportions vary with location and season, zooplankton contribute bulk of dietary carbon</td>
<td>van der Lingen (2002)</td>
<td></td>
</tr>
<tr>
<td>Peru</td>
<td></td>
<td>Smaller zooplankton cf. <em>E. ringens</em>; By number phytoplankton dominate but provide &lt;2% of dietary carbon</td>
<td>Espinoza et al. (2009)</td>
<td></td>
</tr>
<tr>
<td><em>Spratelloides delicatulus</em></td>
<td>Delicate round herring</td>
<td>Kenya</td>
<td>Juvenile round herring: Zooplankton and zoobenthos only</td>
<td>Mavuti et al. (2004)</td>
</tr>
<tr>
<td><em>Sprattus sprattus</em></td>
<td>European sprat</td>
<td>West Scotland</td>
<td>Older sprat: Mainly copepods and cladocera but also appendicularia (<em>Oikopleura spp.</em>), no fish larvae cf. sympatric herring</td>
<td>(de Silva 1973)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>S. North Sea Fish eggs</td>
<td>Pommeranz (1981)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>North Sea All sizes of juvenile sprat: Zooplanktivorous</td>
<td>Last (1987)</td>
</tr>
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<td></td>
<td></td>
<td></td>
<td>S. Baltic All sizes of sprat: Zooplanktivorous; copepods (<em>Temora longicornis</em> &amp; <em>Pseudocalanus spp.</em> ) and cladocera (<em>Bosmina maritima</em>) being preferred</td>
<td>(Casini <em>et al.</em> 2004)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Irish Sea Fish eggs dominate diet early in the year</td>
<td>Fox et al. (2012), Plirú et al. (2012), Ellis &amp; Nash (1997)</td>
</tr>
</tbody>
</table>

ORDER: Clupeiformes; FAMILY: Dussumieriidae

*Dussumieria acuta* Rainbow sardine Various Review: Mainly crustacea, larger fish also take phytoplankton; Teleost prey can be important and may be responsible for most of the fat deposition in rainbow sardine which occurs seasonally | Nair (1973) |
<table>
<thead>
<tr>
<th>Species</th>
<th>English name</th>
<th>Location</th>
<th>Diet – stomach contents or other method stated</th>
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</thead>
<tbody>
<tr>
<td><em>Dussumieria elopsoides</em></td>
<td>Slender rainbow sardine (Rainbow sardine)</td>
<td>Various</td>
<td>Review: Early studies suggested diet was mainly planktivorous, sometimes also including small fish (<em>Stolephorus</em> spp.), copepods (<em>Paracalanus, Acartia</em> and <em>Oithona</em> spp.), also shrimp (<em>Lucifer hanseni</em>), crab zoa and megalopa, larvae of <em>Squilla &amp; Acetes</em> spp., bivalve larvae &amp; chaetognaths, also phytoplankton. Larval prawns and stomatopods when abundant.</td>
<td>Nair (1973)</td>
</tr>
<tr>
<td><em>Etrumeus sadina</em> {teres}</td>
<td>Red-eye round herring</td>
<td>NW Atlantic</td>
<td>Zooplankton, pelagic fish larvae</td>
<td>Refs cited in James (1988)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>East China Sea</td>
<td>By weight: Copepods (<em>Calanoida, Candacia armata</em>), decapod larvae &amp; fish</td>
<td>Bowman et al; (2000)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Mainly calanoid copepods, also Oncaeidae and decapod larvae</td>
<td>Tanaka et al. (2006)</td>
</tr>
<tr>
<td><strong>ORDER: Clupeiformes; FAMILY: Pristigasteridae</strong></td>
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<tr>
<td><em>Ilisha Africana</em></td>
<td>West African ilisha</td>
<td>Lagos</td>
<td>Penaid prawns, fish fry</td>
<td>Façade &amp; Olaniyan (1972)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Lagos offshore</td>
<td>Wide range of crustacean zooplankton, fish eggs &amp; larvae, opisthobranchs</td>
<td>Marcus (1986)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Quo Iboe estuary,</td>
<td>Decapoda, mysids, eucarids, fish eggs &amp; larvae, polychaetes, nematodes. Cannibalism noted</td>
<td>King (1993)</td>
</tr>
<tr>
<td><em>Ilisha Africana</em> con/td</td>
<td>West African ilisha</td>
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<td></td>
<td></td>
<td>Ghana</td>
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<td></td>
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<tr>
<td><strong>ORDER: Clupeiformes; FAMILY: Engraulidae</strong></td>
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<tr>
<td></td>
<td>(Striped anchovy)</td>
<td>NW Atlantic</td>
<td>By weight: Copepods, mysids, <em>Neomysis Americana</em>, decapod larvae</td>
<td>Bowman et al. (2000)</td>
</tr>
<tr>
<td><em>Anchovia clupeoides</em></td>
<td>Zabaleta anchovy</td>
<td>NE Columbia</td>
<td>Copepods, detritus</td>
<td>Duque &amp; Acero (2003)</td>
</tr>
<tr>
<td>Species</td>
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<tr>
<td><em>Cetengraulis mysticetus</em></td>
<td>Pacific anchoveta</td>
<td>Gulf of Panama</td>
<td>Diatoms important in all sized fish; adults contained sediment indicating bottom feeding, few small copepods</td>
<td>Bayliff (1963) cited in James (1988)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Isotopes: Anchovy rely more n zooplankton than phytoplankton</td>
<td>Monteiro et al. (1991)</td>
</tr>
<tr>
<td><em>Engraulis encrasicolus</em></td>
<td>European anchovy</td>
<td>Mediterranean</td>
<td>Mainly copepods</td>
<td>Tudela &amp; palomera (1997)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>W. Baltic</td>
<td>Diatoms (<em>Coscinodiscus</em> spp.), crustacea, including cumacea</td>
<td>Schaber et al. (2010)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>North and Baltic Seas</td>
<td>Copepods, malacostracan larvae, fish larvae</td>
<td>Raab et al. (2011)</td>
</tr>
<tr>
<td><em>Engraulis japonicus</em></td>
<td>Japanese anchovy</td>
<td>East China Sea</td>
<td>Copepods; Oncaecidae, calanoids, lesser amounts of decapod and cirripede larvae. Evidence for positive selection of Oncaecidae</td>
<td>Tanaka et al. (2006)</td>
</tr>
<tr>
<td><em>Engraulis mordax</em></td>
<td>Californian (Northern) anchovy</td>
<td>California coast</td>
<td>Indiscriminate filter feeding, piscivory &amp; cannibalism noted</td>
<td>Baxter (1966)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Gulf of California</td>
<td>Phytoplankton (<em>Coscinodiscus, Rhizosolenia</em> and <em>Thalassionema</em> spp.), small amounts of crustacean; dietary particle size separation from sympatric Pacific sardine (<em>S. sagax</em>).</td>
<td>López-Martínez et al. (1999)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>British Columbia</td>
<td>Euphausiids, copepods, decapod larvae</td>
<td>Hart (1973)</td>
</tr>
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<td></td>
<td></td>
<td>Peru</td>
<td>Diatoms</td>
<td>Espinoza et al. (2009)</td>
</tr>
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<td>Species</td>
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<td></td>
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<td>Baja, northern and southern California</td>
<td>Wide range of zooplankton; copepods and euphausiids, also pelagic worms, thaliaceans, appendicularia, fish eggs and larvae</td>
<td>Loukashkin (1970)</td>
</tr>
<tr>
<td><em>Engraulis ringens</em></td>
<td>Peruvian anchovy</td>
<td>Peru</td>
<td>Copepods, Phytoplankton (diatoms); planktonic crustacean – proportions vary spatially and temporally. Fish eggs and larvae also ingested, cannibalism observed</td>
<td>de Mendiola (1989), Alamo (1989), Pauly et al. (1989)</td>
</tr>
<tr>
<td><em>Setipinna taty</em></td>
<td>Scaly hairfin anchovy (half-fin anchovy)</td>
<td>Bohai Sea</td>
<td>By weight: Decapoda (<em>Acetes chinensis</em>), mysids, chaetognaths (<em>Sagitta crassa</em>). Young fish take more copepods</td>
<td>Hong (1990)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Central Yellow Sea</td>
<td>Crustacea, copepods (<em>Paracalanus parvus, Calanus sinicus, Labidocera euchaeta, Euphausia pacifica</em>). Less polychaetes, gastropod and bivalve larvae</td>
<td>Guo et al. (2010)</td>
</tr>
</tbody>
</table>

ORDER: Perciformes; FAMILY: Ammodytidae

<p>| | | Gulf of Maine | By weight: Copepods (<em>Calanus, Pseudocalanus, Temora, Tortanus spp.</em>), chaetognaths (<em>Sagitta elegans</em>) | Meyer et al. (1978) |
| <em>Ammodytes dubius</em> | Northern sand-lance | Scotian Shelf | By volume: Copepods, polychaete larvae, euphausiids, lesser amounts of crustacean larvae, larvaceans, etc. | Scott (1973) |
| <em>Ammodytes marinus &amp; A. tobianus</em> | Lesser sand-eel &amp; Small sand-eel | North Sea | Mainly copepods and cladocerans, also anchovy eggs | Roessingh (1957) cited in Reay (1970) |</p>
<table>
<thead>
<tr>
<th>Species</th>
<th>English name</th>
<th>Location</th>
<th>Diet – stomach contents or other method stated</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Ammodytes marinus</em></td>
<td>Lesser sand-eel</td>
<td>North Sea</td>
<td>Mainly copepods, some fish larvae, annelids, invertebrate eggs, crustacean larvae, some diet variation with size of sandeel; diatoms found in guts of small <em>A. marinus</em></td>
<td>Macer (1966)</td>
</tr>
<tr>
<td><strong>ORDER: Perciformes; FAMILY: Carangidae</strong></td>
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</tr>
<tr>
<td><em>Chloroscombrus orqueta</em></td>
<td>Pacific bumper</td>
<td>Colombia</td>
<td>Detritus, zoobenthos, nekton</td>
<td>López-Peralta &amp; Arcila (2002)⁷</td>
</tr>
<tr>
<td></td>
<td>(Round scad)</td>
<td>East China Sea</td>
<td>Planktonic crustacea, mainly copepods, shrimp (<em>Squillidae alima</em>), euphausiids (<em>E. pacifica</em>), and other fish (<em>Benthosema pterotum</em>). Seasonal variability noted</td>
<td>Ri-jin et al. (2012)</td>
</tr>
<tr>
<td><em>Trachurus japonicus</em></td>
<td>Japanese jack mackerel</td>
<td>Kyushu</td>
<td>Juvenile mackerel: Copepods (<em>Paracalanidae</em> &amp; <em>Clausocalanidae</em>, <em>Oncaea</em> and <em>Corycaeus</em> spp.)</td>
<td>Hirota et al. (2004)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>East China Sea</td>
<td>Mainly calanoid copepods, also decapod &amp; cirripede larvae</td>
<td>Tanaka et al. (2006)</td>
</tr>
<tr>
<td><strong>ORDER: Perciformes; FAMILY: Scombridae</strong></td>
<td></td>
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</tr>
<tr>
<td><em>Rastrelliger kanagurta</em></td>
<td>Indian mackerel</td>
<td>Karwar, India</td>
<td>Copepods, diatoms, dinoflagellates, tinitinnids, molluscan larvae, decapod larvae, copepod nauplii, cirripede nauplii &amp; larvae</td>
<td>Noble (1962)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Various</td>
<td>Review: Previous studies showed wide range of diet, mainly zooplankton with some phytoplankton. Presence of fish eggs and larvae noted in some studies. Some studies claim change in diet with size of fish but others failed to support this.</td>
<td>George (1964)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Iran</td>
<td>Copepods and molluscs</td>
<td>Avazpour et al.</td>
</tr>
<tr>
<td><strong>ORDER: Atheriniformes; FAMILY: Atherinidae</strong></td>
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</tbody>
</table>

⁷ Pacific bumper is considered a demersal species in this reference
<table>
<thead>
<tr>
<th>Species</th>
<th>English name</th>
<th>Location</th>
<th>Diet – stomach contents or other method stated</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Kenya</td>
<td>Juvenile silverside: Zooplankton and zoobenthos only</td>
<td>Mavuti et al. (2004)</td>
</tr>
<tr>
<td><strong>ORDER: Beloniformes; FAMILY: Exocoetidae</strong></td>
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<tr>
<td><em>Exocoetus monocirrhus</em></td>
<td>Barbel flying fish</td>
<td>Eastern Pacific</td>
<td>Copepods; Barbel flying fish appear to selective euchaetids from available prey</td>
<td>van Noord et al. (2013)</td>
</tr>
<tr>
<td><em>Exocoetus volitans</em></td>
<td>Tropical two-winged flying fish</td>
<td>Tropical Atlantic</td>
<td>By number: Copepods but also amphipods, coelenterates, pteropods, cephalopods, nematodes, fish eggs; suggestion that <em>E. volitans</em> selects larger copepods from available prey field</td>
<td>Evans &amp; Sharma (1963)</td>
</tr>
<tr>
<td><em>Hirundichthys speculiger</em></td>
<td>Mirrorwing flying fish</td>
<td>Tropical Atlantic</td>
<td>Often unrecognisable digested remains, digestion rapid</td>
<td>Evans &amp; Sharma (1963)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Eastern Pacific</td>
<td>Copepods (Calanoida and Cyclopoida), amphipods, larvacea, medusae, nudibranchs, fish larvae; diet appears more generalist cf. <em>E. monocirrhus</em></td>
<td>van Noord et al. (2013)</td>
</tr>
<tr>
<td><em>Parexocoetus brachypterus</em></td>
<td>Sailfin flying fish</td>
<td>North Carolina</td>
<td>By volume: Copepoda, (<em>Sargassum</em> in fish collected near weed), unidentified crustacean remains, unidentified fish remains, also chaetognaths</td>
<td>Casazza (2008)</td>
</tr>
<tr>
<td><strong>ORDER: Beloniformes; FAMILY: Hemiramphidae</strong></td>
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<td></td>
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<tr>
<td>Species</td>
<td>English name</td>
<td>Location</td>
<td>Diet – stomach contents or other method stated</td>
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<tr>
<td><em>Hemiramphus brasiliensis</em></td>
<td>Ballyhoo halfbeak</td>
<td>Cuba, Puerto Rico</td>
<td>By volume: Sea-grasses and epiphytes, fish (<em>Jenkinsia spp.</em>). Plant material is ground by the gastric mill the Hemiramphidae lacking a stomach. Florida Seagrass, cladocera, amphipods, copepods, decapods, siphonophores, less molluscs, polychaetes, fish eggs and larvae.</td>
<td>Randall (1967); Sierra et al. (1994) cited in FishBase</td>
</tr>
<tr>
<td><em>Hyporhamphus quoyi</em></td>
<td>Quoy’s garfish</td>
<td>Gulf of Mannar &amp; Paulk Bay</td>
<td>Sea grass (<em>Cymodocea spp.</em>), algae (<em>Cladophora &amp; Chaetomorpha spp.</em>), diatoms. Occasional polychaetes (<em>Nereis &amp; Perinereis spp.</em>).</td>
<td>Talwar (1962)</td>
</tr>
<tr>
<td><em>Rhynchorhamphus</em> {<em>Hyporhamphus</em>} <em>georgii</em></td>
<td>Long billed halfbeak</td>
<td>Gulf of Mannar &amp; Paulk Bay</td>
<td>Diet varies with maturity: Maturing fish; Sea grass (<em>Cymodocea spp.</em>), algae, diatoms, polychaetes. Spawning fish; Pteropods (<em>Creseis acicula</em>), bivalve larvae, copepods, decapod larvae, diatoms. Spent fish; copepods (<em>Acartia erythraea</em>), forams, some mollusc larvae.</td>
<td>Talwar (1962)</td>
</tr>
</tbody>
</table>

ORDER: Osmeriformes; FAMILY: Osmeridae

<table>
<thead>
<tr>
<th>Species</th>
<th>English name</th>
<th>Location</th>
<th>Diet – stomach contents or other method stated</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mallotus villosus</td>
<td>Capelin</td>
<td>British Columbia</td>
<td>Euphausiids, copepods, polychaetes, larval fish</td>
<td>Hart (1973)</td>
</tr>
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<td></td>
<td></td>
<td>Lawrence</td>
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<tr>
<td></td>
<td></td>
<td>Bering Sea</td>
<td>Copepods, euphausiids</td>
<td>Naumenko (1984) cited in FishBase</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Barents Sea</td>
<td>Copepods (<em>Calanus finmarchicus</em>) amphipoda (<em>Parathemisto abyssorum</em>) euphausiids (<em>Thysanoessa raschii</em>)</td>
<td>Ajiad &amp; Pushchaeva (1992)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Barents Sea</td>
<td>Mainly calanoid copepods, increasing amounts of euphausiids and appendicularia in larger capelin</td>
<td>Huse (1996)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Sea of Okhotsk</td>
<td>Zooplankton</td>
<td>Kuznetsova (1997) cited in FishBase</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Newfoundland</td>
<td>Copepods, hyperiid amphipods, euphausiids, larvaceans &amp; chaetognaths.</td>
<td>O'Driscoll et al. (2001)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Gulf of Alaska</td>
<td>By weight: Increasing dominance of euphausiids in larger capelin</td>
<td>Wilson (2009)</td>
</tr>
<tr>
<td>Thaleichthys pacificus</td>
<td>Eulachon</td>
<td>Gulf of Alaska</td>
<td>By weight: Increasing dominance of euphausiids in larger eulachon</td>
<td>Wilson (2009)</td>
</tr>
<tr>
<td>Species</td>
<td>English name</td>
<td>Location</td>
<td>Diet – stomach contents or other method stated</td>
<td>Reference</td>
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</tr>
<tr>
<td>Euphausiidae</td>
<td>Krill</td>
<td>Various</td>
<td>Review: Different interpretations of functioning of the feeding apparatus. Stomach contents usually macerated and hard to visually identify. Many euphausiids able to change feeding mode depending on conditions.</td>
<td>Mauchline (1980a)</td>
</tr>
<tr>
<td>Euphausia superba</td>
<td>Antarctic krill</td>
<td>Scotia Sea</td>
<td>Diet herbivorous but suggested coprophagy occurring in krill swarms</td>
<td>Antezana &amp; Ray (1984)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Weddell Sea</td>
<td>Summer: Phytoplankton, diatoms (<em>Thalassiosira</em>, <em>Nitzschia spp.</em> &amp; <em>Pennatae</em>)</td>
<td>Maciejewska (1993)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>South Georgia</td>
<td>Evidence of cannibalism during austral winter</td>
<td>Nishino &amp; Kawamura (1994)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>South Georgia</td>
<td>Juvenile krill during autumn: Dinoflagellates, ciliates &amp; small copepods preferentially selected</td>
<td>Atkinson &amp; Snyder (1997)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>South Georgia</td>
<td>Fatty acid profiles of krill reflected spatial differences in available prey, diatoms in Bellingshausen Sea, protozoa and copepods at S. Georgia</td>
<td>Cripps et al. (1999)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>South Georgia</td>
<td>17-99% of gut contents of heterotrophic origin</td>
<td>Perissinotto et al. (2000)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Maguerite Bay</td>
<td>Fatty acids and stomach contents: Krill switch to include copepods in diet during austral winter</td>
<td>Ju &amp; Harvey (2004)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>SW Atlantic</td>
<td>Diatoms, tintinnids, heterotrophic dinoflagellates</td>
<td>Schmidt et al. (2006)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Southern Ocean</td>
<td>Krill exploit under-ice biota (diatoms) during austral winter; krill in open water exploit copepods &amp; detritus</td>
<td>O’Brien et al. (2011) &amp; Flores et al. (2012)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Scotia Sea</td>
<td>Stable isotopes: Diet of krill more herbivorous than expected</td>
<td>Atkinson (2012), Stowasser et al. (2012)</td>
</tr>
<tr>
<td>Meganyctiphanes norvegica</td>
<td>Northern krill</td>
<td>Throughout range</td>
<td>Review: Feeds epibenthically but also in upper water column during diel vertical migrations; diet mainly diatoms &amp; copepods, proportions vary with season &amp; location. Phytoplankton tends to be more important during spring bloom, copepods more important in autumn. Adults take more copepods cf. younger krill.</td>
<td>Schmidt (2010)</td>
</tr>
<tr>
<td>Species</td>
<td>English name</td>
<td>Location</td>
<td>Diet – stomach contents or other method stated</td>
<td>Reference</td>
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</tr>
<tr>
<td></td>
<td>Gulf of Maine</td>
<td>DNA-based: copepods, phytoplankton, salps, possible benthic associated organisms</td>
<td>(Cleary et al. 2012)</td>
<td></td>
</tr>
</tbody>
</table>
Most fish produce planktonic eggs (notable exceptions being sandeels and herring but their larvae are planktonic) so it is not surprising that fish eggs and larvae often appear in SPF diets. Because SPF can also be numerous several workers have wondered whether this predatory pressure might affect the survival rates of either the SPF themselves (cannibalism) or the recruitment success of other species (Cushing 1980).

A number of workers have reported egg cannibalism by anchovy (references cited in Hunter and Kimbrell (1980) and Table 11. Anchovy consume eggs through filtering and will also attack larvae by biting. Egg chorions may be recognisable in the guts of the consumer for up to 8 h but larvae are digested beyond recognition in around 30 mins. Examination of field samples indicated that feeding continued throughout the day and night and between 42 and 88% of fish contained the remains of anchovy eggs. Hunter and Kimbrell (1980) estimated that the fraction of daily egg production consumed by cannibalism was around 17%, or about a third of total estimated daily mortality. Cannibalism was cited as a possible reason for high field mortality rates of anchovy eggs compared with some other species (Ciechomski and Sanchez 1984). The significance of cannibalism against other sources of predation mortality for Peruvian anchovy, E. ringens, was examined by Alheit (1987). Estimates of cannibalism mortality were around one fifth of the total daily egg mortality of 68%. This estimate is very similar to that of Hunter and Kimbrell (1980). Even higher estimates have been produced within egg patches (Valdés et al. 1987), for example 70% of total egg mortality in S. African anchovy (E. capensis). There was also some evidence for a non-linear density-dependent response. This would be an important finding in relation to population dynamics where density-dependent mechanisms are required in order to stabilise population abundances in the long-term. This was examined further by Szeinfeld (1991) in relation to both cannibalism and consumption of anchovy (E. capensis) eggs by sardine (Sardinops ocellatus). Overall sardine were estimated to be responsible for up to 56% of egg mortality while cannibalism accounted for around 6%. Again there was some evidence that egg cannibalism might follow a sigmoid-shaped curve (known as a functional Type III curve) although this was not totally conclusive. Off Argentina these processes have also been studied by Pájaro et al. (2007). They found cannibalism accounted for 15-33% of total egg mortality and also observed the upward part of a sigmoid functional response curve but similarly failed to find evidence for saturation (Szeinfeld 1991). Whether cannibalism really provides a density-dependent stabilising mechanism thus remains an open question. Egg cannibalism is relatively easy to detect for anchovy because of the unusual oval-shaped eggs produced by this species. However cannibalism has also been observed in other SPF. For example in the Baltic, sprat (S. sprattus) (Tsikliras et al. 2005)eggs can be found in sprat stomachs, sometimes in high numbers. Köster and Möllman (2000) estimated that this might account for between 15 to 60% of standing stock. Cannibalism was suggested to be an important source of sprat egg mortality in the Bornholm Basin, especially in years when low salinity and oxygen increased predator-prey overlap.

Consumption of the eggs and larvae of other species by SPF has also been suggested as an explanation for periods of strong or weak recruitment. For example, in the North Sea the so-called “gadoid-outburst”, when recruitment of species such as whiting and cod was
particularly high, coincided with a period when the herring stocks had been reduced to a low level. This led Cushing (1980), and subsequently others (Huse et al. 2008, Fauchald 2010), to speculate that predation by herring on eggs and larvae of gadoid fish might be sufficient to exert controls on their recruitment. However these ideas are largely based on correlations between stock-abundance time-series and the timing of the two events, the decrease in herring and the increase in gadoids does not match precisely, either spatially or temporally (Hislop 1996). What is really needed to test such ideas are field data on consumption and production rates. Daan et al. (1985) examined the predation pressure exerted on the egg stages of plaice \((P.\ platessa)\) and cod \((G.\ morhua)\) by herring \((C.\ harengus)\) in the North Sea. They found that younger herring (ages 2 and 3) consumed most eggs and that these age classes were more prevalent in the southern North Sea (older herring in the northern North Sea were consuming mainly euphausiids). However, the overall proportions of total egg production consumed were estimated at only 0.7 to 1.9% for plaice and 0.04 to 0.19% for cod. Daan et al. (1985) therefore considered that predation by herring was not important enough to be affecting the recruitment success of these other species. They did however caution that the herring stock abundance in the years studied (1980, 1982 & 1983) was well below historical levels and that it would be worthwhile repeating the exercise if the stock recovered. In the Irish Sea, Fox et al. (2012) detected plaice DNA in around 77% of herring \((C.\ harengus)\) stomachs sampled at a plaice spawning ground and in 75% of sprat \((S.\ sprattus)\) stomachs. Plirú et al. (2012) went on to calculate that the sprat predation alone was sufficient to account for over 70% of the estimated daily mortality experienced by the plaice eggs. However, this situation may be somewhat unusual because plaice spawn early in the year when there are few alternate plankton prey in the water (Fox et al. 2012). As well as sprat and herring, other SPF can be important as in the western central North Sea where anchovy were reported to be particularly significant consumers of plaice eggs (Garrod and Harding 1981). The impact of SPF predation on the eggs and larvae of other later spawning species in the Irish and North Seas is not yet known but seems worth investigating further. On George’s Bank, the spatial distribution of larval gadoids can overlap with that of herring \((C.\ harengus)\) suggesting that predation interactions could be important in some years (Garrison et al. 2000). Perhaps the clearest example comes from the Baltic where consumption of cod eggs by herring and sprat has been shown to be an important component of controls on cod year-class success in the Baltic (Köster and Schnack 1994, Köster et al. 2001).

SPF species will also predate the larvae of other SPF species. For example in the Barents Sea sandeel \((A.\ marinus)\) and herring \((C.\ harengus)\) both take capelin \((M.\ mallotus)\) larvae and appear to alternate searching for these prey with hunting for alternates such as euphausiids (Huse and Toresen 1995, Godiksen et al. 2006). Although the chorions of fish eggs are somewhat resistant to digestion and can be found in stomach contents (Daan et al. 1985, Ellis and Nash 1997, Plirú et al. 2012), larvae are usually rapidly digested (Godiksen et al. 2006, Hallfredsson et al. 2007, Christensen 2010). The relative paucity of records of fish larvae in SPF stomach contents may thus simply reflect our inability to detect the true level of this form of predation. This gap in knowledge is significant with regard to the development of food-web models which usually only include estimates of predation based on visual stomach
analyses. Whether predation rates exerted by SPF on eggs and larvae are sufficient to “set” subsequent year-class strength has been hotly debated (Houde 2008). Clearly the mortality experienced by the post-larval stages can alter the rank-order of year-class strengths but for some species at least there is evidence that relative year-class strength is fixed by the end of the larval stage (Bannister et al. 1974, Brander and Houghton 1982, van der Veer et al. 2000, Oeberst et al. 2009). Complex feeding relationships including both cannibalism and intra-guild competition are a considerable challenge for food-web models (discussed in more depth Section 3.3). For example, the interactions between herring (C. harengus), sprat (S. sprattus), sandeels (Ammodytidae spp.) and anchovy (E. encrasilocus) in the North Sea led Engelhard et al. (2013b) to conclude that, with present knowledge, it is almost impossible to predict the medium- to long-term trajectories of SPF under different fishing pressure scenarios. The situation is further complicated by climate-change which is leading to alterations in the SPF species mix in areas like the North Sea (Beare et al. 2004, Petitgas et al. 2012).

3.2. What preys on SPF

The importance of SPF as prey for other marine and terrestrial predators is well known and they are often termed “forage” fish (see Section 1). A Google search using the terms “small pelagic fish + predation” yields 2,750 returns; “forage fish + predation” yields 7,790 results and “forage fish + foodwebs” yields 5,080 results. It is clearly impractical to report on all of this literature so I present first a summary of predation on SPF egg and larval stages and then selected references to illustrate the range of predators which SPF support. The role of SPF within food-webs is discussed in more detail in Section 3.3.

Several species of SPF produce benthic eggs e.g. Atlantic herring (C. harengus) spawn over gravel and lay multi-layered mats of eggs which are attractive to gadoids (de Groot 1980, Toresen 1991, Høines and Bergstad 1999, Torniainen and Lehtiniemi 2008) and sandeels (Rankine and Morrison 1989). Several researchers have speculated whether the compensatory stock-recruit relationships observed for many herring stocks might be generated at the egg stage (Wood 1981, Zheng 1996). Because the area of suitable spawning habitat is often limited such relationships could arise due to a combination of anoxia in lower egg layers when SSB is high (Wood 1981) and predation when SSB is low (Zheng 1996). However, studies where the abundance of recently hatched larvae have been measured suggest reasonably linear relationships with spawning stock biomass (Heath 1993, Fox 2001, Nash and Dickey-Collas 2005, Richardson et al. 2010). This implies that density-dependent processes are not acting strongly during the egg stage {although see Saville (1973) for a possible counter-example}. Regardless of these arguments, egg mortality due to predation by gadoids such as haddock (M. aeglefinus) can be substantial. This has been suggested as an explanation, in combination with fishing pressure, for switching between gadoid and clupeid dominated states which has been observed in several North Atlantic ecosystems, including George’s Bank (Richardson et al. 2011). In contrast with most stocks of Atlantic herring, Pacific herring (C. pallasi) lay their eggs in shallower inshore habitats (Hay et al. 2009). Mass spawning by Pacific herring attracts a wide range of predators including birds (Bishop and Green 2001, Therriault et al. 2009). Because of their shallow location, losses of eggs due
to physical disturbance by waves and storms can also occur (Norcross et al. 2001). Sandeel lay eggs in the sediment and because of their inaccessibility to sampling little appears to be known about the levels of mortality they suffer or the factors responsible. Capelin (Mallotus villosus) deposit demersal eggs on sediments in water of between 20-100 m depth. Sand and gravel substrates are preferred, often in areas of high current flow which helps oxygenate the eggs. Capelin eggs are predated by gadoid fish such as haddock, by diving ducks (references cited in Dolgov (2002)) and can also be subjected to cannibalism.

Planktonic eggs and larvae are produce by many SPF species and will be preyed upon by a wide range of pelagic organisms (Bunn et al. 2000). There is no reason to think that SPF eggs and larvae are at any more risk from predation than other similarly sized planktonic organisms although the filter-feeding habits of some SPF, such as anchovies, may mean that rates of cannibalism on their eggs are higher than for other species (see Section 3.1). The escape reactions of larvae of several species of SPF have been studied in the laboratory and, as mentioned in Section 3.2, escape success tends to decline with food limitation but increase as the larvae grow larger (von Westernhagen and Rosenthal 1976, Webb 1981, Bailey and Batty 1984, Yin and Blaxter 1987, Batty 1989, Fuiman 1989, Skajaa et al. 2004, Christensen 2010, Masuda 2011). However, as eggs and larvae develop they also become more visible and this may increase the risk of predation, albeit temporarily (Folkvord and Hunter 1986). There have also been several studies of how shoaling behaviour (exhibited by many SPF) develops and its role as an anti-predator defence (Gallego and Heath 1994, Morgan et al. 1994, Gallego et al. 1995, Misund et al. 2005, Masuda 2011).

Field studies of the predators of SPF larvae have also been conducted (Alvariño 1980, Lynam et al. 2005, Godiksen et al. 2006, Hallfredsson and Pedersen 2009, Pedersen et al. 2009) but, as discussed in Section 3.1, researchers have struggled with the problem of detecting rapidly digested fish larvae in predator stomachs (Heath 1992). Several field studies on pelagic fishes have also used otolith microstructure to estimate larval age (Panfili et al. 2001) in order to test hypotheses relating growth rates to mortality (Takasuka et al. 2003, Takahashi and Watanabe 2004, Dominique et al. 2007).

A summary of some of the reported predators of post-larval SPF is given in
Table 12. As previously mentioned there is a vast amount of literature on this topic and the examples given are only intended to allow the reader an overview of the range of predators which SPF support. In general the role of SPF as prey has been determined from stomach content analyses but examination of faeces has also been widely applied, particularly with marine mammals and seabirds. For fish, samples for direct stomach content analysis are often available from commercial catches or scientific surveys and this approach has also been applied to cetaceans caught accidentally in fisheries (Bastida and Lichtschein 1988, Alonso et al. 1998). Stomach contents of stranded cetaceans have also been reported although these animals may have been starved or sick before stranding and results may not reflect normal diet patterns (Santos et al. 2004). As well as direct identification of whole prey, the otoliths of post-larval fish often remain recognisable in both stomach contents and faeces. Otolith shape allows identification of the prey to species and the size of the otolith can be used to estimate the length and age (Prime and Hammond 1990, McKinnon 1992, Hammond et al. 1994, Tollit and Thompson 1996, Andersen et al. 2007, Labansen et al. 2007). Nevertheless there are problems with this method as the rate of otolith digestion varies with species (Christiansen et al. 2005, Labansen et al. 2007). Conversion of the numbers and sizes of otoliths found in stomachs or faecal remains to absolute estimates of the amounts of prey consumed is acknowledged as being difficult. As with stomach content analyses described in Section 3.1, modern molecular methods are also being applied to scat analysis (Casper et al. 2007). Early attempts used anti-sera but results were variable due to different specificities and digestion rates of target proteins from different prey (Pierce et al. 1990). Anti-body based methods have now been largely superceded by DNA-based techniques (Deagle et al. 2009). Unlike fish, euphausiids do not contain hard-parts which can be recovered although identifiable carapace remains can be found in some scats (Reid 1995). Stomach contents can also be obtained for direct analysis by stomach lavage (Fraser and Hofmann 2003). This procedure has been applied to penguins and does not injure the birds. One problem with all these methods is that they can only be used during the breeding season when the animals are accessible to researchers. Prey consumption rates during at-sea periods are generally poorly understood. The amounts of krill taken by individual cetaceans have been estimated from fore-stomach analysis of specimens from commercial or “scientific” whaling programs. These results have been combined with estimates of population abundance and bioenergetics modelling to estimate overall consumption e.g. by baleen whales in the Southern Ocean (Reilly et al. 2004). For other species such as seals and birds, combinations of laboratory studies and modelling have been used to estimate krill ingestion (Boyd 2002). Although the estimates obtained from these approaches are highly uncertain, they should be taken into account in fisheries manmangement (Reilly et al. 2004).

As well as losses to predation and fisheries, some SPF have been affected by problems with water quality. This largely applies to inshore species such as menhaden which can accumulate potentially toxic algae and related toxins from blooms (Del Rio et al. 2010, Mary Hilbern et al. 2013). There have also been reported mass fish kills of inshore SPF linked to *Pfiesteria piscicida* although the causative pathways probably involve multiple stressors (Dykstra and Kane 2000, Burkholder and Marshall 2012). Whilst the egg and larval stages of SPF are known to be infected by parasites which can affect embryo survival
Stratoudakis et al. 2000, Meneses et al. 2003) and larval feeding success (Heath and Nicoll 1991) there appear to be relatively few studies of the impacts of parasites and disease on older fish. The presence of parasites has however been used to discriminate SPF fish stocks (MacKenzie 2002, Timi and Poulin 2003, Chavez et al. 2007).
Table 12: Some studies reporting predators where SPF are an important component of the diet. Where reference states “cited in” it has not been possible to check all details in the original paper.

<table>
<thead>
<tr>
<th>Species</th>
<th>English name</th>
<th>Location</th>
<th>Reported predators</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Brevoortia patronus</strong></td>
<td>Gulf menhaden</td>
<td>Mississippi</td>
<td>Fish: Longnose gar (<em>Lepisosteus osseus</em>)</td>
<td>Goodyear (1967)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Texas</td>
<td>Fish: Red drum (<em>Sciaenops ocellatus</em>) — menhaden in diet during spring</td>
<td>Scharf &amp; Schlicht (2000)</td>
</tr>
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<td></td>
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</tr>
<tr>
<td><strong>Brevoortia tyrannus</strong></td>
<td>Atlantic menhaden</td>
<td>Delaware</td>
<td>Fish: Bluefish (<em>Pomatomus saltatrix</em>) – fed on young menhaden</td>
<td>Grant (1962)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>N Carolina</td>
<td>Fish: Striped bass (<em>Morone saxatilis</em>)</td>
<td>Manooch (1973)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>N Carolina</td>
<td>Fish: Weakfish (<em>Cynoscion regalis</em>), less important in diet than anchovies</td>
<td>Merriner (1975)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Chesapeake Bay</td>
<td>Bluefish (<em>Pomatomus saltatrix</em>); Striped bass (<em>Morone saxatilis</em>); Weakfish (<em>Cynoscion regalis</em>); Wiren &amp; Brandt (1995)</td>
<td></td>
</tr>
<tr>
<td><strong>Clupea harengus</strong></td>
<td>Atlantic herring</td>
<td>Mid-Atlantic Bight – Gulf Maine</td>
<td>Wide range including Cetacea: humpback (<em>Megaptera novaeangliae</em>); finback (<em>Balaenoptera physalus</em>); minke (<em>Balaenoptera acutorostrata</em>); pilot (<em>Globicephala spp.</em>) whales; white-sided dolphin (<em>Lagenorhynchus acutus</em>); harbour porpoise (<em>Phocoena phocoena</em>); Pinnipeds: harbour seal (<em>Phoca vitulina</em>) Birds: Northern gannet (<em>Morus bassanus</em>); Shearwater (species not stated); Fish: Silver hake (<em>Merluccius bilinearis</em>); cod (<em>Gadus morhua</em>); spiny dogfish (<em>Squalus acanthias</em>)</td>
<td>Refs cited in Overholtz et al. (1991)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Baltic Sea</td>
<td>Fish: Cod (<em>Gadus morhua</em>)</td>
<td>Sparholt (1994)</td>
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<tr>
<td></td>
<td></td>
<td>Irish Sea</td>
<td>Fish: Spurdog (<em>Squalus acanthias</em>); tope (<em>Galeorhinus galeus</em>)</td>
<td>Ellis et al. (1996)</td>
</tr>
<tr>
<td>Species</td>
<td>Location</td>
<td>Notes</td>
<td>References</td>
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<tr>
<td>George’s Bank</td>
<td>Fish: Silver hake (<em>Merluccius bilinearis</em>); winter skate (<em>Raja ocellata</em>); spiny dogfish (<em>Squalus acanthias</em>); cod (<em>Gadus morhua</em>)</td>
<td>Tsou &amp; Collie (2001)</td>
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<tr>
<td>N. North Sea</td>
<td>Cetacea: Harbor porpoise (<em>Phocena phocena</em>) – seasonal variability noted and herring not as important as sandeels in diet</td>
<td>Santos et al. (2004)</td>
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<tr>
<td>North Sea</td>
<td>Birds: Gannet (<em>Morus bassanus</em>)</td>
<td>Hamer et al. (2007)</td>
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<tr>
<td>Barents Sea</td>
<td>Cetacea: Minke whale (<em>Balaenoptera acutorostrata</em>)</td>
<td>Lindstrøm et al. (2002)</td>
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<tr>
<td><strong>Opisthonema oglinum</strong></td>
<td>Atlantic thread herring</td>
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<tr>
<td><strong>Sardina pilchardus</strong></td>
<td>N Carolina</td>
<td>Fish: Weakfish (<em>Cynoscion regalis</em>), more common in fish aged 2 to 4</td>
<td>Merriner (1975)</td>
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</tr>
<tr>
<td><strong>Sardinella aurita</strong></td>
<td>Portugal</td>
<td>Cetacea: Common dolphin (<em>Delphinus delphis</em>)</td>
<td>Silva (1999)</td>
<td></td>
</tr>
<tr>
<td><strong>S. American pilchard</strong></td>
<td>Peru</td>
<td>Cetacea: Dusky dolphin (<em>Lagenorhynchus obscurus</em>)</td>
<td>McKinnon (1992)</td>
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</tr>
<tr>
<td></td>
<td>California</td>
<td>Fish: Thresher shark (<em>Alopias vulpinus</em>) – sardine was less important in diet cf. <em>E. mordax</em></td>
<td>Preti et al.(2001) &amp; Preti et al. (2004)</td>
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</tr>
<tr>
<td><strong>S. Africa</strong></td>
<td>Pinnipeds: Fur seal (<em>Arctocephalus pusillus</em>) – sardine of some importance at one breeding site</td>
<td>Mecenero et al. (2006)</td>
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<tr>
<td><strong>S. Africa</strong></td>
<td>Birds: African penguins (<em>Spheniscus demersus</em>)</td>
<td>Crawford et al. (2006)</td>
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<tr>
<td>Gulf of Mexico</td>
<td>Birds: Elegant tern (<em>Thalasseus elegans</em>), Heermann’s gull (<em>Larus heermanni</em>), California brown pelican (<em>Pelecanus occidentalis californicus</em>)</td>
<td>Velarde et al. (2013)</td>
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<tr>
<td><strong>Sprattus fuegensis</strong></td>
<td>Falkland sprat</td>
<td>Tierra del Cetacea: Commerson’s dophin (<em>Cephalorhynchus</em>)</td>
<td>Bastida &amp; Lichtschein</td>
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</tr>
<tr>
<td>Fish</td>
<td>Habitat</td>
<td>Feeding</td>
<td>Authors</td>
<td></td>
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<tr>
<td>Herring</td>
<td>Argentina</td>
<td>Birds: Magellanic penguins (<em>Spheniscus magellanicus</em>) – more sprat taken at southern breeding colonies</td>
<td>Scolaro et al. (1999)</td>
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<tr>
<td></td>
<td>Falkland Is. (Malvinas)</td>
<td>Fish: Spiny dogfish (<em>Squalus acanthias</em>)</td>
<td>Laptikhovsky et al. (2001)</td>
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<tr>
<td>Sprattus sprattus</td>
<td>Sprat</td>
<td>Baltic Sea</td>
<td>Fish: Cod (<em>Gadus morhua</em>)</td>
<td>Sparholt (1994)</td>
</tr>
<tr>
<td></td>
<td>N. North Sea</td>
<td>Cetacea: Harbor porpoise (<em>Phocena phocena</em>) – seasonal variability noted and sprat not as important as sandeels in diet</td>
<td>Santos et al. (2004)</td>
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</tr>
<tr>
<td></td>
<td>North Sea</td>
<td>Birds: Guillemot (<em>Uria aalge</em>) – switching from sandeel to sprat may explain recent reproductive failures</td>
<td>Wanless (2005)</td>
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<tr>
<td></td>
<td></td>
<td>Birds: Gannet (<em>Morus bassanus</em>)</td>
<td>Hamer (2007)</td>
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</tbody>
</table>

**ORDER: Clupeiformes; FAMILY: Dussumieriidae**

<table>
<thead>
<tr>
<th>Fish</th>
<th>Habitat</th>
<th>Feeding</th>
<th>Authors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Etrumeus whiteheadii</td>
<td>Whitehead’s round herring</td>
<td>S. Africa</td>
<td>Pinnipeds: Fur seal (<em>Arctocephalus pusillus</em>) – herring of some importance at one breeding site</td>
</tr>
</tbody>
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**ORDER: Clupeiformes; FAMILY: Pristigasteridae**

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<th>Fish</th>
<th>Habitat</th>
<th>Feeding</th>
<th>Authors</th>
</tr>
</thead>
</table>

**ORDER: Clupeiformes; FAMILY: Engraulidae**

<table>
<thead>
<tr>
<th>Fish</th>
<th>Habitat</th>
<th>Feeding</th>
<th>Authors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anchoa spp.</td>
<td>Anchovies</td>
<td>N Carolina</td>
<td>Fish: Weakfish (<em>Cynoscion regalis</em>)</td>
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<tr>
<td>Anchoa mitchilli</td>
<td>Bay anchovy</td>
<td>N Carolina</td>
<td>Striped bass (<em>Morone saxatilis</em>)</td>
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<td>Chesapeake Bay</td>
<td>Fish: Bluefish (<em>Pomatomus saltatrix</em>); Striped bass (<em>Morone saxatilis</em>); Weakfish (<em>Cynoscion regalis</em>)</td>
<td>Hartman &amp; Brandt (1995)</td>
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<tr>
<td>Engraulis anchoita</td>
<td>Argentine anchovy</td>
<td>Argentina</td>
<td>Cetacea: Dusky dolphin (<em>Lagenorhynchus obscurus</em>) – anchovy was the most important prey item by weight</td>
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<td></td>
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<td>Argentina</td>
<td>Birds: Magellanic penguins (<em>Spheniscus magellanicus</em>) – more anchovy taken at northern breeding colonies</td>
</tr>
</tbody>
</table>

\(^8\) Anchovy cited as *Engraulis ringens* in this reference
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<td></td>
<td>S. Africa</td>
<td></td>
<td>Pinnipeds: Fur seal (<em>Arctocephalus pusillus</em>) – anchovy of some importance at one breeding site</td>
<td>Mecenero et al. (2006)</td>
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<tr>
<td><strong>Engraulis encrasicolus</strong></td>
<td>European anchovy</td>
<td>Portugal</td>
<td>Cetacea: Common dolphin (<em>Delphinus delphis</em>) – anchovy not as important in diet as <em>S. pilchardus</em></td>
<td>Silva (1999)</td>
</tr>
<tr>
<td><strong>Engraulis mordax</strong></td>
<td>Californian anchovy</td>
<td>S California Bight</td>
<td>Birds: Brown pelican (<em>Pelecanus occidentalis</em>)</td>
<td>Sunada et al. (1981)</td>
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<td></td>
<td>NE Pacific</td>
<td></td>
<td>Fish: Pacific hake (<em>Merluccius productus</em>) – forage fish abundance may affect predation by hake on juvenile salmon (<em>Oncorhynchus spp.</em>)</td>
<td>Emmett &amp; Sampson (2007)</td>
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<td></td>
<td>California</td>
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<td>Birds: Common murres (<em>Uria aalge</em>)</td>
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<td>Gulf of Mexico</td>
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<td>Birds: Elegant tern (<em>Thalasseus elegans</em>), Heermann’s gull (<em>Larus heermanni</em>), California brown pelican (<em>Pelecanus occidentalis californicus</em>)</td>
<td>Velarde et al. (2013)</td>
</tr>
</tbody>
</table>

ORDER: Perciformes; FAMILY: Ammodytidae

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9 Anchovy cited as *Engraulis encrasicolus* in this reference
10 Anchovy cited as *Engraulis encrasicolus* in this reference
<table>
<thead>
<tr>
<th>Genus</th>
<th>Species</th>
<th>Location</th>
<th>Predators</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ammodytidae</td>
<td>Sandeels</td>
<td>Mid-Atlantic Bight – Gulf Maine</td>
<td>Wide range of predators including Cetacea: humpback (<em>Megaptera novaeangliae</em>); finback (<em>Balaenoptera physalus</em>); minke (<em>Balaenoptera acutorostrata</em>); pilot (<em>Globicephala spp.</em>) whales; white-sided (<em>Lagenorhynchus acutus</em>) dolphins; harbour porpoise (<em>Phocoena phocoena</em>); Seals: harbour (<em>Phoca vitulina</em>); Birds: Shearwater (species not stated); Black legged kittiwake (<em>Rissa tridactyla</em>); Fish: Silver hake (<em>Merluccius bilinearis</em>); cod (<em>Gadus morhua</em>); spiny dogfish (<em>Squalus acanthias</em>)</td>
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<tr>
<td></td>
<td></td>
<td>NW Atlantic</td>
<td>Pinnipeds: Harp (<em>Phoca groenlandica</em>), Hooded (<em>Cystophora cristata</em>), Grey (<em>Halichoerus grypus</em>) and Harbour (<em>Phoca vitulina</em>) seals</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>George’s Bank</td>
<td>Fish: Silver hake (<em>Merluccius bilinearis</em>); winter skate (<em>Raja ocellata</em>); haddock (<em>Melanogrammus aeglefinus</em>); spiny dogfish (<em>Squalus acanthias</em>); cod (<em>Gadus morhua</em>)</td>
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<tr>
<td></td>
<td></td>
<td>North Sea</td>
<td>Birds: Gannet (<em>Morus bassanus</em>)</td>
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<tr>
<td></td>
<td></td>
<td>Faroe Is.</td>
<td>Fish: Saithe (<em>Pollachius virens</em>) – spatial and temporal variations in diet noted</td>
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</tr>
<tr>
<td>Ammodytes dubius</td>
<td>Northern sand lance</td>
<td>NW Atlantic</td>
<td>Fish: Herring (<em>Clupea harengus</em>)</td>
<td></td>
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<tr>
<td>Ammodytes marinus</td>
<td>Lesser sandeel</td>
<td>Shetland</td>
<td>Birds: Arctic tern (<em>Sterna paradisaea</em>)</td>
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<td></td>
<td>N. North Sea</td>
<td>Cetacea: Harbour porpoise (<em>Phocoena phocoena</em>) – some Greater sandeel (<em>Hyperoplus spp.</em>) Identified in diet</td>
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<td>ORDER: Beloniformes; FAMILY: Exocoetidae</td>
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<tr>
<td>Exocoetidae</td>
<td>Flying fishes</td>
<td>Various</td>
<td>Fish: Yellowfin (<em>Thunnus albacares</em>) and skipjack (<em>Katsuwonus pelamis</em>) tunas</td>
<td></td>
</tr>
<tr>
<td>Exocoetus volitans</td>
<td>Tropical two-wing flying fish</td>
<td>Indian Ocean</td>
<td>Fish: Lancetfish (<em>Alepisaurus ferox</em>), swordfish (<em>Xiphias gladius</em>) and yellowfin tuna (<em>Thunnus albacares</em>) but in low amounts</td>
<td></td>
</tr>
</tbody>
</table>

Payne et al. (1990); Refs cited in Overholtz et al. (1991)
Hamill & Stenson (2000)
Tsou & Collie (2001)
Hamer et al. (2007)
Homrum et al. (2012)
Fogarty et al. (1991)
Monaghan et al. (1989)
Santos et al. (2004); MacLeod et al. (2007)
Alverson (1963); Maldeniya (1996)
Potier et al. (2007)
**ORDER: Osmeriformes; FAMILY: Osmeridae**

<table>
<thead>
<tr>
<th>Species</th>
<th>Capelin</th>
<th>Location</th>
<th>Fish: Cod (<em>Gadus morhua</em>)</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Mallotus villosus</em></td>
<td></td>
<td>Newfoundland</td>
<td></td>
<td>Lilly (1991)</td>
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<td></td>
<td></td>
<td>Iceland</td>
<td></td>
<td>Magnússon &amp; Pálsson (1991)</td>
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**ORDER: Euphausiacea; FAMILY: Euphausidae**

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<tr>
<th>Species</th>
<th>Pacific krill</th>
<th>Throughout range</th>
<th>Whales: Fin (<em>Balaenoptera physalis</em>), sei (<em>Balaenoptera borealis</em>)</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Euphausia pacifica</em></td>
<td></td>
<td>Alaska</td>
<td>Fish: Walleye pollock (<em>Theragra chalcogramma</em>)</td>
<td>Refs cited in Mauchline (1980b)</td>
</tr>
<tr>
<td>Region</td>
<td>Wildlife</td>
<td>Reference</td>
<td></td>
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<tr>
<td>--------------------------------</td>
<td>-------------------------------------------------------------------------------------------</td>
<td>------------------------------------</td>
<td></td>
<td></td>
</tr>
<tr>
<td>E. Antarctica</td>
<td>Birds: Adélie penguins (<em>Pygoscelis adeliae</em>)</td>
<td>Clarke et al. (2002);</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mid- to northern Western Antarctic Peninsula</td>
<td>Birds: Adélie penguins (<em>Pygoscelis adeliae</em>) – In continental Antarctica Adélie penguins rely less on <em>E. superba</em> and more on Antarctic silverfish (<em>Pleuragramma antarcticum</em>) and <em>Euphausia crystallorophias</em></td>
<td>Fraser &amp; Hoffmann (2003)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Meganyctiphanes norvegica</em></td>
<td>Northern krill</td>
<td>Refs cited in Mauchline (1969); Mauchline (1980b); Simard &amp; Harvey (2010)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Various</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
3.3. The role of small pelagics as forage fish in marine foodwebs
The key role of SPF as forage fish has long been known (Table 12). This has led to many studies looking at (1) the direct affects of SPF availability on higher predators (2) the development of foodweb models.

3.3.1. Direct effects on predators of changes in SPF abundance, distribution and nutritional quality
Bottom-up effects of changes in SPF abundance and distribution have been noted in many ecosystems but particularly in the Pacific. In some cases predators can either change their diet or foraging patterns to deal with prey shortages but other species seem to have less flexibility. Strong fluctuations in the abundance of key prey are typical of so called “wasp-waist” systems where a limited number of species, usually SPF, are found at the intermediate trophic levels (Cury et al. 2000). Intermittent declines in the availability of Peruvian anchoveta (E. ringens), linked with warm-water El Niño years (Laws 1997), have direct impacts on seabirds such as the Humboldt penguin (Spheniscus humboldti), Peruvian boobies (Sula variegata) and Guanay cormorants (Phalacrocorax bougainvillii) for which anchovy are normally the main prey (Weimerskirch et al. 2012). Humboldt penguins respond to prey shortages by foraging more extensively but breeding failure will still occur in years when anchovy are particularly scarce (Hays 1986). Strong El Niño events have also led to mass failure rearing failure of guano birds and subsequent substantial declines in numbers (Duffy 1983). Peruvian (Sula variegata), Blue-footed (S. nebouxii) and Masked (S. dactylatra) boobies have been shown to have different responses to El Niño events. Peruvian boobies seemed unable to switch prey and their abundance at breeding sites was directly related to the abundance of anchovy. In contrast, Blue-footed boobies, which normally prefer to forage on anchovy in the coastal upwelling zone (Zavalaga et al. 2008), seemed able to switch to other coastal fish. Masked boobies responded to anchovy shortages by switching to more oceanic prey (Jaencke and Goya 2000). There will also be differences in how seabird species respond to changes in SPF abundance because of differences in their feeding behaviour. For example, in the Gulf of Mexico, elegant terns (Thalasseus elegans) and Hermann’s gulls (Larus heermannii) feed mainly on the pre-recruit stages of the SPF whilst brown pelican (Pelecanus occidentalis californicus) target adult fish (Velarde et al. 2013). Fluctuations in oceanic conditions such as El Niño/La Niña are a natural phenomenon and have been occurring for at least 6,000 years although their intensity has varied over time (Vargas et al. 2006, Zapata et al. 2013). Animals living in these ecosystems have clearly adapted to deal with these natural fluctuations in prey so that their populations can persist over long periods. However, the additional impacts of commercial fisheries, and other human activities, may exacerbate population declines and potentially limit seabird recovery rates (Hays 1986, Vargas et al. 2006, Velarde et al. 2013).

Thompson et al. (2012) presented evidence for similar bottom-up effects on a number of top predators in the California upwelling system including Cassin’s auklet (Ptychoramphus aleuticus), common murre (Uria aalge), humpback whale (Megaptera novaeangliae) and Chinook salmon (Oncorhynchus tshawytscha). Path analysis suggested that the seasonality and strength of the upwelling affects the predators via indirect links through primary and secondary production.

Direct relationships between food availability and seabird breeding success have also been found in the Benguela up-welling system. The African penguin (Spheniscus demersus) preys mainly on anchovy (E. encrasicolus) and sardine (S. sagax) and trends in the number of
chicks reared per pair of birds have been related to the available biomass of prey (Crawford et al. 2006). Penguin breeding rates have been estimated to be sufficient to prevent population decline (assuming adult survival also improved somewhat) when the spawning stock biomass of the SPF was above two million tons but would be insufficient at lower SSBs. As well as taking measures to limit adult mortality, the authors recommended that management of the purse-seine fisheries should take into account the need to leave adequate biomass to support the penguin colonies (Crawford et al. 2006). Similar considerations apply to several other seabirds which rely on SPF in the southern Benguela (Crawford 2004) including Cape gannet Morus capensis, Cape cormorant Phalacrocorax capensis and swift tern Sterna bergii (Crawford 2004).

Effects of changes in abundance and size of SPF on predators have also been reported from non-up-welling systems. In the North Sea impacts on seabirds, particularly species which feed their chicks on sandeel (Ammodytidae), have been studied. Concerns arose when reduced seabird reproduction was noted in some areas where sandeel fisheries were operating (Bailey et al. 1991, Rindorf et al. 2000). However, modelling suggested that recruitment success for sandeel (A. marinus) is naturally highly variable so periods of poor seabird breeding success might be expected (Poloczanska et al. 2004). Furthermore, sandeel recruitment appears to be negatively correlated with winter sea temperatures (Frederiksen et al. 2004) which had been rising (Good et al. 2007). Recent results suggest that both sandeel quantity and nutritional quality are critical for seabird breeding success (Wanless et al. 2004) (Frederiksen et al. 2006) and that both quantity and quality appear to be affected by changes in the zooplankton, changes which in turn are linked with oceanographic conditions (Frederiksen et al. 2004, Wanless et al. 2005, Frederiksen et al. 2007). Spatial sandeel fisheries closures have been introduced around key seabird breeding colonies in the northern North Sea and do appear to have had some beneficial effects, although observed responses are confounded with the environmental effects mentioned above (Daunt et al. 2008). Similar links have been made between rates of starvation of harbour porpoise (Phocoena phocoena) and good and poor years for sandeels off the north-east coast of Scotland (MacLeod et al. 2007). Scenarios of climate change suggest a positive underlying trend for sea temperatures in the North Sea over the coming decades (Clark et al. 2003) although there will be regional variability (Becker and Pauly 1996) and periods of stasis or cooling (Wiltshire and Manly 2004) linked with the North Atlantic atmospheric oscillation (Woehrling et al. 2005). The rise in average temperatures in the coming decades is expected to affect all levels of the North Sea ecosystem including the distribution, recruitment and growth of temperature sensitive forage fish such as anchovy (potentially positive effects (Lenoir et al. 2011) and sandeel (potentially negative effects (Arnott and Ruxton 2002, Heath et al. 2012).

Sandeel are also important in the central and southern North Sea, particularly around the Dogger Bank where they are important prey for fish such as whiting (Merlangius merlangus), lesser weaver (Echichthys vipera), grey gurnard (Eutrigla gurnardus), plaice (Pleuronectes platessa) and haddock (Melanogrammus aeglefinus). Engelhard et al. (2013a) studied the body condition of these predators in relation to local availability of sandeel. They
found direct effects on predator body condition comparing years when sandeel were more or less abundant.

In the Antarctic, krill (*E. superba*) is a major component of the diet of Gentoo (*Pygoscelis papua*) and macaroni (*Eudyptes chrysolophus*) penguins as well as other pelagic foraging birds such as grey-headed (*Diomedea chry sostoma*) and black-browed (*D. melanop hns*) albatross. The availability of krill can vary substantially between years resulting in longer foraging trips for parent birds and use of alternate prey and this had significant impacts on the weight of the chicks (Croxall *et al.* 1999). Macaroni penguin seemed more resilient to fluctuations in krill abundance as they switched to consuming amphipods in years when krill were scarce. Male and female Adélie penguins (*Pygoscelis adeliae*) take alternate turns to forage and guard the young and if food shortages occur at this stage chick survival can be reduced (Clarke *et al.* 2002). Later on the chicks can be left alone for longer and both parents forage. The extent and timing of break-up of sea-ice also appears critical for this species and led to total breeding failure in 1994/95. The authors further commented that development of a krill fishery along the shelf edge could impact female birds more heavily as they spend more time foraging than males during the guarding stage.

In their study of the California upwelling system, Thompson *et al.* (2012) used a simple trophic pathway from primary, via secondary and tertiary production then to predators such as seabirds and whales. However, foodweb interactions in these systems are complex and may be modified via poorly studied components such as jellyfish (Brodeur *et al.* 2011). Worldwide there has been considerable concern expressed over the potential impacts of increasing abundance of gelatinous predators as they are generally seen as trophic dead-ends reducing the availability of productivity to fish, seabirds and mammals (Richardson *et al.* 2009). Jellyfish can also exert strong predation pressure on fish early life stages including SPF and may impact their recruitment success (Purcell *et al.* 1993, Purcell *et al.* 1994, Lynam *et al.* 2005). However, despite much publicity there is considerable debate over whether the abundance of jellyfish and the frequency of blooms is really increasing (Haddock 2008, Brotz *et al.* 2012, Condon *et al.* 2012, Boero 2013).

It is not unreasonable to ask whether these relationships be used to guide management plans for SPF fisheries. Cury *et al.* (2011) conducted a meta-analysis on the effects of forage fish availability on seabird breeding success. They found that breeding success changes in a non-linear fashion with prey abundance and suggested that a rough rule would be that management plans should try and keep SPF abundance above one-third of the observed long-term maximum. However, the authors also cautioned that this rule-of-thumb should not be applied blindly but would need to take into consideration local conditions such as spatial management plans. There are clearly potential trade-offs between the conservation of predators such as seabirds and the sustainability of the fisheries, including the livelihoods of the people involved (Hannesson 2013b). What the balance between the two should be is not a scientific question but a societal and political issue. The role of science is to provide the best available evidence as to the consequences of adopting different management strategies (Walters and Martell 2004b).
The next extension from statistical analyses of the relationships between trends in predator and prey abundances has been the development of food-web models. Although these models present a more realistic picture of how foodwebs function, they are also more demanding of data. Because of the multiple interactions in more complex food-web models, the results can also be difficult to interpret. The simpler statistical analyses described above and food-web modelling should therefore be seen as complementary approaches to gaining a fuller understanding of how marine ecosystems function.

3.3.2. Foodweb models including SPF

Models of marine foodwebs have been in development for well over 30 years. Several extensions of single-species age-structured virtual population models have been constructed (known as MSVPA or multi-species virtual population assessments) including for George’s Bank (Tsou and Collie 2001), the Baltic (Neuenfeldt 2000), the E. Bering Sea (Livingston and Jurado-Molina 2000), the North Sea (Kempf et al. 2006) and the east coast of the USA (Garrison et al. 2010). MSVPA models generally include a sub-set of the full food-web because of the data demands of the approach (Sparre 1991). Results from MSVPA models did profoundly alter perceptions of the role of predation in regions such as the North Sea but their main practical application has been to adjust the natural mortality rates in single-species VPA models. MSVPA has also illustrated how changes in the abundance of predators such as grey gurnard (Eutrigla gurnardus) may affect other species (Floeter et al. 2005). Although there have been further developments of MSVPA (Garrison et al. 2010), it is probably fair to say that the data demands of these models have meant that it has not been as widely applied or developed as was originally hoped. In addition, many of the observed changes in real ecosystems appear to be generated through predation impacts on early life stages i.e. effects on recruitment success. MSVPA does not appear very suitable for dealing with these processes (Pope 1991).

An alternative approach is to treat all the age classes of each species as a single biomass pool. Early representations of foodwebs took the form of simple static flow diagrams representing the basic linkages between predators and prey (Figures 27). Further studies on consumption rates and the bioenergetics of predators and prey led to the development of more detailed steady-state representations of areas such as the Peruvian upwelling (Figure 28). Because these representations assumed that predators and prey are homogenously mixed through the system further spatial extensions were required to deal with changing predator-prey interactions related to warmer and cooler periods (Jarre et al. 1991). Homogenous vat models also tend to predict much stronger top-down and bottom-up interactions than are thought to occur in nature. Ecopath models (described below) deal with this issue in a slightly different manner based on foraging arena theory (Walters and Martell 2004c).

In some cases SPF can also act as important agents of energy transfer between ecosystems which are often treated separately e.g. estuarine and coastal zones (Deegan 1993, Maes and Ollevier 2000). Similarly meso-pelagic SPF play important roles in vertical nutrient fluxes between the photic zone and deeper waters (McClimattie and Dunford 2003). These processes can all be modelled but the temporal and spatial scales must be carefully considered and appropriate levels of aggregation applied (Heath 2012).
Figure 27: Representation of the Antarctic foodweb – redrawn from Hart (1942). The weight of the connecting arrows indicates the relative importance of the prey in the diet of the predator. Box thickness of the key SPF has been increased for emphasis.
Improvements in data availability have led to the development of mass-balance models for many marine ecosystems. The basic principle of mass-balanced models is that the sum of biomass (or other energy related units) consumed by predators (and removed by fisheries) must be balanced by the flow of biomass through the foodweb and ultimately by the amounts available from primary production (Coll et al. 2009). Perhaps the most widely used modelling tool for simulating foodwebs in this manner is EWE (Ecopath with Ecosim) although it is by no means the only approach which can be adopted (Heath 2012). As mentioned before, VPA and MSVPA are age-structured whereas EWE models usually amalgamate all age-classes into single units (in recent versions of EWE it is possible to split...
functional-groups into multi-stanzas such as pre and post-recruits). Building an EWE model proceeds as follows:-

- Set up a representation of the food-web based on diet preference information, often gained from stomach content analyses. At this step it is also necessary to decide on the taxonomic resolution of the model. Ecopath deals with functional groups i.e. species can be merged on the basis that they act in a similar manner in trophic terms. This is often necessary to reduce the model complexity or because data are lacking for certain species. Fishing fleets also need to be defined at this stage.
- The Ecopath model must then be set up with estimates of at least some of the biomasses. Ecopath can estimate some missing parameters but requires data on other parameters in order to achieve this.
- The next step is to enter energetic information for each functional group. This is factors such as the average biomass/production and consumption/production ratios for each group. These values can be taken from the scientific literature, databases such as FishBase, or estimated using approximation equations based on information such as organism size and average temperature in the system being modelled.
- It is then necessary to balance the model. This means that over the whole food-web the amount of energy units (biomass, carbon etc.) entering at the base of the food-web through primary production must be sufficient to account for the sum of what is taken out of the food-web (consumption) and losses due to metabolism. Balance is achieved by modifying the bioenergetics parameters and the foraging-arena related variable V (“vulnerability”). Achieving a balanced model is often the most challenging stage of construction. This does not mean that the biomass of all functional groups is fixed in time, biomass accumulation or depletion can occur but the model checks that this is within reasonable bounds. Even once balanced it is essential to carefully check the model to make sure the bioenergetics and biomass parameters are reasonable for the type of functional group and ecosystem e.g. that the turnover times for large marine mammals do not imply unfeasibly short reproductive periodicity (Link 2000).
- The process is essentially a top-down web in that unaccounted for production is normally recycled into a “detritus” pool.
- Once a balanced model has been obtained it can be run forward in time in Ecosim and fitted against available time-series of observations e.g. of fish biomass derived from fisheries surveys. There are multiple adjustments which can be made to improve model fit including the number of parameters estimated. An important consideration is balancing the penalty of additional parameters against the improvement in fit. This is normally done by consideration of information theory measure such as AIC (Akaike information criterion, (Mackinson et al. 2009a).
- Primary production anomalies can also be extracted and further compared with potential environmental drivers which are thought to influence primary production e.g. the Pacific Decadal Oscillation Index (Guénette et al. 2006). Alternatively
EWE models have been linked with process driven models of primary production to produce full end-to-end models although this approach has not been widely implemented (Steele and Ruzicka 2011).

- The Ecosim model can then be used to simulate the consequences on the food-web of changing things such as fishing pressure and fleet structure. Such simulations can be used to explore policy (management) options in a wider Ecosystem-based Approach than traditionally assumed by single-species stock-assessment and projection models. It is important here to note that multispecies models are highly unlikely to replace single-species tools in providing fisheries advice. Single-species models are perfectly adequate in many cases for reconstructing stock trajectories, estimating relationships between fishing pressure and stock growth, producing stock projections (at least in the short-term) and generating target and reference points. Rather multi-species models should be viewed as an additional tool available to the fisheries scientist that allows wider questions to be addressed (Christensen and Walters 2011).

- EWE models can be further expanded to have a spatial element using EcoSpace. This sort of extension is beginning to be used for exploring the consequences of management measures such as no-take zones.

- Basic EWE models are deterministic but Monte-Carlo runs can also be made allowing parameter values to vary within certain limits. This can be useful for exploring the sensitivity of the results (Coll et al. 2009).

It must be emphasised that developing an Ecopath/Ecosim model for anything more than a small sea area is a major research exercise (Coll et al. 2009). In particular the time required for compiling and checking data should not be under-estimated and EWE models can only really be constructed for systems where there is already a good understanding of the food-web structure. As with any modelling system EWE has a number of issues which users need to be aware of (Walters et al. 1997, Christensen and Walters 2004, Coll et al. 2009) but the availability of the software and relatively user-friendly interface have meant it has become widely used and tested. To date at least 120 EWE models have been developed (www.ecopath.org) and many of these demonstrate the key roles of SPF in the foodwebs - a few examples from larger marine ecosystems are given below:-

Baltic Sea (Harvey et al. 2003): An Ecopath model for the foodweb in 1974 was developed using MSVPA estimates for cod (G. morhua), herring (C. harengus) and sprat (S. sprattus) and run forward using Ecosim. Multi-stanza splitting was applied to sprat and herring. The model suggested a food-web with strong predator–prey linkages. Biomass changes at higher trophic levels, principally cod, caused affected influenced lower trophic levels, similar to trophic cascades. The model was further used to explore different fisheries management options under contrasting productivity regimes (Hansson et al. 2007).

Benguela (Heymans and Baird 2000): Trophic models were constructed in Ecopath and another package (Netwrk). SPF species included anchovy (E. japonicus) and sardine (S. ocellatus). The model demonstrated “wasp-waist” type dynamics with both top-down and bottom-up effects of changes in abundance of the species in the mid-trophic levels. The
relative amounts of primary production exported to the fishery and consumed within the food-web were estimated. The Ecopath model was subsequently developed further and used to examine how the food-web had responded to the combination of environmental drivers and fisheries (Heymans et al. 2004). EWE models for the Benguela have also been used to derive ecosystem-level indicators for use in developing an ecosystem-based approach to fisheries in the region (Cury et al. 2005).

British Columbia (Ainsworth et al. 2002): Ecopath with Ecosim models were constructed to represent the foodweb in four time periods 1750, 1900, 1950 and 2000. The functional group forage fish included sandlance plus pilchard, anchovy, capelin, shad and smelts, herring comprised a separate group. The model was subsequently used to evaluate potential ecosystem restoration under scenarios of release from fisheries pressure (Ainsworth et al. 2008) and climate effects (Ainsworth et al. 2011).

Gulf of St. Lawrence (Savenkoff et al. 2006, Savenkoff et al. 2004): Mass balance models constructed to represent foodweb in mid 1980s, mid-1990s and early 2000s. Principal SPF included were Atlantic herring (C. harengus) and capelin (M. villosus). Results suggest that predation was main source of herring mortality during all time-periods. Cod (Gadus morhua) and redfish (Sebastes spp.) were replaced by cetacea and seals as the main predators on herring from the mid-1980s to early 2000s in the northern Gulf. In the southern Gulf, large cod and harp seals were the main predators during the mid-1980s while predation and fishing mortality were of similar importance during the mid-1990s. Fishing effects on forage species since the early 1990s seemed to counter the expected increases in biomass of these species following the net decrease in biomass of the demersal species and the ensuing drop in predation. The net decrease in biomass of demersal piscivores due led to a drop in predation from the mid-1980s to the mid-1990s and an ecosystem dominated by small-bodied pelagic species and marine mammals in the northern and southern Gulf. Capelin is an important prey for many fish species such as cod Gadus morhua and redfish Sebastes spp. in the northern Gulf and cod and mackerel Scomber scombrus in the southern Gulf. Capelin are also important prey for for marine mammals (cetacea and seals). Capelin was the main fish predator of small and large zooplankton in the northern Gulf during each time period and was also the main prey consumed by fish and marine mammals.

Gulf of Mexico (Manickchand-Heileman et al. 1998): An Ecopath model was presented representing the system in the early 1990s. The main SPF represented were herrings (Clupeidae and Engraulidae) which both provide prey for other species and are fished in this region. Among consumers the herrings have the highest biomass and production:biomass ratios in the model after infauna and zooplankton. The model was subsequently improved and used to examine different management options with relation to the shrimp fishery (Arreguin-Sanchez et al. 2004).

Mediterranean (Coll et al. 2007): Model focussed on the 1990s after a collapse of the anchovy stock and decline in other small pelagics. The main SPF included in the model were
European anchovy (*E. encrasicolus*) and sardine (*S. pilchardus*). The results suggested that bottom, mid-water and beam trawling had the highest impacts on both target and non target ecological groups. On the contrary, purse seining only had medium to low impacts and fishing activity did not significantly impact cetaceans, marine turtles or sea birds. The model was subsequently reformulated and used to compare the role of coastal upwelling in sustaining foodwebs in several systems including Peru, Chile, S. Africa, Namibia and the NW Mediterranean (Coll *et al.* 2006).

Newfoundland and the southern Labrador shelf (Pitcher *et al.* 2002): Ecopath models were set up for four historical periods 1985, 1995, 1990 and 1450. SPF groups represented include capelin (*Mallosus villosus*), sand lance (*Ammodytes* spp.) and Atlantic herring (*Clupea harengus*) plus other small pelagics such as shad and argentine (*Argentina silus*) and smelt (*Osmerus mordax*). The ecosystem has undergone significant restructuring over this time. Anthropogenic changes were likely triggered by Basque whaling before 1500, the great auk was driven to extinction by exploitation in the 18th century and in the late 1980s the cod fisheries collapsed.

North Sea (Christensen 1995, Mackinson 2001): Models representing the North Sea foodweb in the 1980s and the historical state (1880s) were constructed. The results show the importance of the Atlantic herring (*C. harengus*) in the 19th century both for the foodweb and for fisheries. By the 1980s the North Sea was a more gadoid dominated system. Among other things the model has since been used to examine long-term management options within a multi-species fishery context (Mackinson *et al.* 2009b).

Norwegian and Barents Sea (Dommasnes *et al.* 2001): Models representing this ecosystem around the late 1990s and 1950s were constructed. The main SPF represented were herring (*C. harengus*), capelin (*M. villosus*), other small pelagic fish and krill. The main predators on the SPF included toothed and baleen whales, seabirds and fish such as cod (*G. morhua*). Some of the data and analysis from Dommasnes *et al.* (2001) was subsequently incorporated into a new EWE model for the Barent’s Sea developed to explore cetacean-fishery interactions (Blanchard *et al.* 2002). Comparisons of two years, 1990 and 1995, demonstrated that shifts in capelin abundance led to changes in diet by predators. When capelin abundance was low the model predicted a shift towards demersal species (saithe, crab, cod etc.) compared with more pelagic species (capelin, polar cod and herring) in the diets when capelin was abundant.

South Georgia shelf (Hill *et al.* 2012b): Balanced models of the system were built with the main SPF being krill (*Euphausia superba*). The models were used to examine possible effects on top-predators of switches from a krill to copepod dominated zooplankton community as might occur under warming. The model highlighted a number of inconsistencies in the data e.g. much higher than expected production/biomass ratios for krill. There were a wide variety of feasible responses to a shift to a copepod dominated system depending on the extent to which intermediate-level predators were able to switch diet. This breadth of potential outcomes serves to emphasise the many gaps remaining in understanding
of the structure and functioning of the ecosystem for this region. The models also suggested consumption of krill by fish might be higher than often assumed.

West Florida Shelf (Okey et al. 2004): an Ecopath model was used to evaluate possible consequences of increasing phytoplankton blooms. Shading led to declines in all functional groups excepting phytoplankton, small copepods, ichthyoplankton, and carnivorous jellyfish. Although groups feeding mainly on phytoplankton benefited, others (mackerel, seabirds, and surface pelagics) also declined due to the presence of benthic primary products in their diet.

There has also been considerable development of size-structured models. This approach differs from age-based and functional group models in that it treats organisms on the basis of their size alone. The theory behind this approach again derives from basic trophic considerations in that there are generally predictable relationships between the size of predators and their prey. This suggests that the abundance of organisms by size-class in the sea will follow so-called “size-spectra” – there is both good theoretical and observational support for this. Given that SPF can also be defined in terms of their size (Section 1), it is possible to use size-based models to make inferences regarding SPF, even though they are not modelled as an explicit group. For example, Blanchard et al. (2012) used a series of such models to examine possible climate-rated changes in fish production across 11 regional seas. The size-spectra models representing the consumers were in turn driven by coupled-biogeochemical models which provided forcing in terms of daily phytoplankton, microzooplankton and detritus biomass density and sea surface and sea floor temperatures. When the coupled models were forced with warming scenarios, declines of 30-60% in potential production were projected from important up-welling zones such as the northern Humboldt and Canary Current. The driver for these changes appeared to be reduced projected densities of phytoplankton and zooplankton. It is important to note that in other areas, such as the Nordic Seas increases in phytoplankton, zooplankton and fish biomass were projected. Fisheries effects were also then incorporated including representations of fisheries targeting SPF species for fishmeal (small pelagics, 1.25–80 g) and for direct human consumption (larger pelagics and demersals, 80g–100 kg). It was suggested that such models could be useful for identifying regions which may be particularly impacted by potential climate change. Similar analyses for the Kuroshio/Oyashio current system in the Pacific were presented by Yatsu et al. (2013)

As can be seen from the previous section there are a wide range of modelling approaches which can be adopted. The inter-relations between these approaches are summarised in (Plagányi 2007) and for some examples of where ecosystem models have been used in providing fisheries advice see FAO (2008). For the North Sea (Figure 29) ICES intends moving towards providing fisheries assessment within a multi-species context based on the stochastic multispecies model (ICES 2013a). Advice for the Baltic will also be presented in a multispecies framework but the foodweb is simpler involving cod, herring and sprat. These emerging approaches recognise that due to foodweb interactions it will be impossible to maintain all species above precautionary single-species reference levels. Target fishing mortalities (F) leading to multi-species F_{msy} (long-term average maximum sustainable yield
across multiple species) are actually higher than single-species based F targets. This is because of feed-backs from top predators to prey. This also raises the challenging argument about whether the management system should be trying to achieve some other outcome, such as maximum sustainable economic yield (MSEY), as opposed to focussing on biomass yields (Pilling et al. 2008, Grafton et al. 2012).

Figure 29: Overview of the important predators and prey in the North Sea SMS model foodweb. Other fish include grey gurnard, North Sea and western horse mackerel, and starry ray. Seabirds include fulmar, gannet, great black-backed gull, guillemot, herring gull, kittiwake, puffin, and razorbill. Seals and porpoises include grey seal and harbour porpoise. An “Other food” pool with constant biomass is included in the model to represent all prey types that are found in the stomachs but that are not modelled explicitly (e.g., crustaceans, mollusks, other prey fish). The colour of the line indicates which predator the species is eaten by, the thickness of the line indicates the biomass removed in this interaction (average from 1963 to 2010).

(Pikitch et al. 2012a) used a number of EWE models to examine the economic importance of SPF in terms of the other fisheries they supported via their role as prey. It was estimated that SPF contribute nearly $17 billion to global fisheries (based on 2006 ex-vessel values) but that the direct catch value was approximately one-third of this total. The supportive value of SPF exceeded the direct catch value in 30 of the 72 ecosystems studied.

3.4. Top-down and bottom-up controls
Foodwebs where there are a limited number of species at the intermediate trophic levels have been termed “wasp-waist” systems (Cury et al. 2000, Hunt Jr and McKinnell 2006). In several systems, particularly in up-welling areas, SPF form the “waist”. The abundance of SPF is often strongly affected by changes in phyto and zooplankton production and these changes in turn affect the abundance of higher predators (see Section 3.2). However, there
can be feed-backs so that the predatory pressure on the SPF may restrict their abundance and in-turn feeding by the SPF might impact zooplankton. Cury et al. (2000) examined this question for a number of different ecosystems and concluded that both top-down and bottom-up controls could be found depending on the ecosystem. SPF predation was sufficient to exert top-down control on zooplankton off South Africa, Ghana, Japan, and in the Black Sea whilst changes in SPF directly affected the abundance of higher predators in the Benguela, Guinea, and Humboldt systems. Yatsu et al. (2005) suggested that both top-down and bottom-up processes might be significant in relation to changes in Japanese sardine (S. sagax/melanostictus) and other pelagic species including chub mackerel (S. japonicus) in the north-western Pacific. Duarte and Garcia (2004) used an EWE model to explore the role of small pelagics in a tropical Caribbean system. Whilst changes in SPF affected top-level predators, a top-down effect from the SPF to plankton was not seen. Thus it seems that the full “was-waist” dynamics may not have a full equivalent in less productive tropical upwelling areas. Cury et al. (2000) went on to discuss how the top-predators in particular had evolved strategies to cope with variable SPF abundance in the “waist” and how fisheries might disrupt the functioning of such “wasp-waist” systems. Fauchald et al. (2011) performed a similar analysis for the North Sea which is normally regarded as a bottom-up driven system (Frederiksen et al. 2006). Fauchald et al. (2011) concluded that there was statistical evidence that herring (C. harengus) exerts both bottom-up control (on seabirds) and top-down control (on zooplankton). In contrast sprat (S. sprattus) exerted bottom-down control on zooplankton but its abundance was not significantly related to that of seabirds. If top-down controls are widespread, then reductions in the abundance of top-predators should lead to increases in the abundance of organisms in the “waist” via trophic-cascades (Verity et al. 2002). There are many examples where trophic cascades appear to have been triggered by fisheries (Springer et al. 2003, Daskalov et al. 2007, Myers et al. 2007, Oguz and Gilbert 2007, Heithaus et al. 2008, Kirby et al. 2009, Walsh et al. 2011, Frank et al. 2013) and in some of these cases increases in the abundance of SPF have been documented. In other cases expected increases in some SPF species were not observed following collapse of demersal piscivore populations e.g. Gulf of St. Lawrence (Savenkoff et al. 2006, Savenkoff et al. 2004). Expected increases in herring (C. harengus) were not observed possibly due to increases in fishing mortality. The mechanisms involved in trophic cascades can be complex involving prey-switching and different predator-prey interactions at different life stages (Springer et al. 2003, Heithaus et al. 2008, Fauchald 2010). Such mechanisms are not necessarily captured in many of the food-web models which have been developed to date.

3.5. Environmental factors limiting SPF productivity

As noted above it is possible to estimate primary production anomalies from Ecopath/Ecosim models and to then attempt to find environmental correlates which in some cases will improve the model fit in a sensible manner e.g. Guénette et al. (2006). The implication is that it is the environment which is driving changes in primary production. However, there has also been a long history of searching directly links between environmental drivers and SPF abundance (Southward et al. 1988, Alheit and Hagen 1997, Klyashtorin 1998, Lluch-Cota et al. 1999, Hollowed et al. 2001, Nagasawa 2001, Brinton and Townsend 2003, MacKenzie and Köster 2004, Norton and Mason 2005, Yatsu et al. 2005, Takasuka et al. 2007, Deriso et
There are numerous problems with these approaches if applied naively including the risks of “data fishing”, probability inflation due to failure to correct for comparisons with multiple environmental factors, failure to correct for autocorrelation in the time-series, failure to appreciate that recruitment time-series derived from virtual-population models can themselves be affected by shifts in natural mortality (Lapointe and Peterman 1991), failure to account for collinearity among environmental variables and potential over-fitting to data. As a consequence many of the correlations which have been published, particularly between fish recruitment and environment indices, have failed to stand-up over time (Deyle et al. 2013) although relationships for species at the northern and southern edges of their ranges appear more robust (Myers 1998). In addition, the strength of interactions between environment and population processes, such as recruitment, can vary depending on the status of the stock itself (Brander 2005). Stock-environment correlations can therefore appear and disappear over time but this does not necessarily mean that the correlations are spurious (Jacobson and McClatchie 2013). In addition, environmental effects can interact with predators, shock events such as pollution, disease and the fisheries themselves creating potentially very complex multifactorial problems (Deriso et al. 2008). Many of the statistical models which have been developed also lack explanatory mechanisms, although some models have been developed from a bottom-up consideration of ecological processes (Lluch-Cota et al. 1999, Rijnsdorp et al. 2009, Peck et al. 2013). While statistical issues, such as auto-correlation and probability inflation, can be dealt with by correct application of methods this can often be difficult for relatively short time-series. Statistical power can also be increased by using meta-analysis (comparing across multiple stocks or regions) and this has yielded some interesting results, for example Ottersen et al. (2013) detected a temperature effect on herring stock-recruitment relationships across all nine stocks examined thus strengthening the hypothesis that this is a real effect. Alheit et al. (2014) also found evidence that the Atlantic Multidecadal Oscillation (AMO) affects the geographic ranges and migrations of several small pelagic species in the north-eastern Atlantic.

The original spawning stock biomass and recruit database compiled by Myers et al. (1995) has formed the basis for many meta-analytical studies including examinations of environment-recruitment relationships (Myers 1998). Ricard et al. (2012) describe recent updates to that database. However, the lack of robust environment relationships at the “individual stock level” is one reason assessment scientists have been reluctant to incorporate environmental signals into their models (Walters and Martell 2004a, Stige et al. 2013). One exception has been the apparently strong effect of temperature on Pacific sardine (S. sagax) recruitment along the west coast of America (see below) which was incorporated into the harvest control rules of the Pacific Fishery Management Council for a period. However, this approach was abandoned when other analyses gave differing results (McClatchie et al. 2010) but that analysis itself is disputed (Lindegren and Checkley 2012, Jacobson and McClatchie 2013). This episode illustrates many of the problems of incorporating environmental data into stock assessments and advice (Walters and Martell 2004a) including arguments over statistical model formulation, over whether environmental parameters, in this case temperature, measured at one location (Scripps Institute of Oceanography pier) can be
representative of the ambient experience of a stock over a wide geographical range and whether correlations between recruitment and environmental variables can be trusted when the under-lying mechanisms are unknown.

There are many well-known examples where the environment is thought to be affecting SPF abundance (Laws 1997, Lehodey et al. 2006, Beamish 2008, Hollowed et al. 2008, Yatsu et al. 2013). In the Pacific catches of anchovies (Engraulis japonicus) have fluctuated synchronously across the region being high in the 1950s through to 1970s, declining in the 1980s and then rebounding in the 1990s. Sardine began to increase throughout the region in the 1970s and was dominant for around two decades before declining again in the 1990s (Kawasaki 1993). The sardine outburst is obvious in the global clupeid catch data (Figure 2) and in Peruvian, Chilean and Japanese SPF landings (Figures 22, 23 & 24). Sardine appear to be able to cope with warmer waters better than anchovy (Lehodey et al. 2006) and records prior to the FAO landings data clearly show these outbursts are not a recent phenomenon. A warm period in the 1930s and 40s saw massive increases in catches of sardine off California, with an equally rapid collapse in the late 1940s (Radovich 1982). A landings ban was imposed by the California Legislature in 1967 but by this time the sardine fishery in southern California had already vanished. The sardine fisheries in the northwest had long since ceased to exist with fish last landed in British Columbia in 1947-1948, in Oregon and Washington in 1948-1949, and in San Francisco Bay in 1951-1952. In the 1980s there was still little agreement over whether the sardine stocks had collapsed due to over-exploitation, climate change or some combination of the two. The concensus now seems to be that synchronous patterns in SPF landings across the Pacific are generated by large-scale atmospheric forcing which leads to changes in ocean temperature with the region switching from “cooler” to “warmer” periods (Kawasaki 1993, Chavez et al. 2003). However the mechanisms seem more complex as Kawasaki (1993) suggested that the outburst was triggered by climate-related improved survival of larvae produced from high-condition parents leading to a series of strong year-classes but the subsequent collapse involved a reduction in parental condition generated by density-dependent processes (Kawasaki and Omori 1995). Whether the California sardine would have persisted had harvest rates been better controlled is not known although its eventual demise may also have been unavoidable (Lindegren et al. 2013). Climate patterns in the Pacific are complex with intermittent short-duration events such as El Ñino years which have significant ecosystem impacts overlaid on long-term multi-decadal oscillations (Cahuin et al. 2009, Overland et al. 2010). “Cooler” and “warmer” periods do not apply across the whole Pacific as the western and eastern areas are out of phase (Chavez et al. 2003) and the ecosystem impacts are also more complicated than simply warmer temperatures favouring one species over another (Kawasaki and Omori 1995, Polovina 2005)(Lindegren et al. 2013). For example, it is unclear why sardine (S. sagax) increased off Japan when local conditions were cooler but increased off California and Peru during warmer, less productive periods (Chavez et al. 2003). Differences between anchovy and sardine in terms of their feeding bioenergetics on larger and smaller zooplankton (see Section 3.1) SPF diets and feeding strategies may be important (Ayón et al. 2011) although
other hypotheses evoke temperature effects on early life growth and survival (Takasuka et al. 2007, Cahuin et al. 2009). Similar links between sea temperature and SPF recruitment have been hypothesised for Pacific herring (Clupea pallasi) but again the mechanisms appear complex. Years of cooler temperatures seem to favour strong recruitment but cold years do not always generate strong year-classes (Nagasawa 2001).

In most cases SPF stocks are affected both by “natural” processes and fishing and it can be very difficult to disentangle the various drivers (Ueber and MacCall 1992, Holmgren-Urba and Baumgartner 1993, Sharp and McLain 1993, Cisneros-Mata et al. 1995, Laws 1997, Hollowed et al. 2001, Norton and Mason 2003, Guénette et al. 2006, Dickey-Collas et al. 2010). However, there is one example where fisheries effects can definitely be discounted. This classic case was provided through examination of scale deposition in anoxic sediments off California. Differences in scale shape allow separation of those from sardine and anchovy whilst the abundance of scales in cores of sediment have allowed reconstruction of the alternating dominance by Pacific sardine (S. sagax) and Californian (Northern) anchovy (E. mordax) over a period of two thousand years, well before any commercial fisheries were established (Figure 30). Such patterns can only be generated by environmental drivers affecting habitat use or population dynamics (Pikitch et al. 2012a).

Figure 30: Reconstructed biomass trends for S. sagax and E. mordax reconstructed from scale deposits in anoxic sediments off Santa Barbara, California (Baumgartner et al. 1992). COPYRIGHT PERMISSION REQUIRED

Another example where fisheries can probably be discounted is long-term changes in the abundance of Antarctic krill (Atkinson et al. 2004). Data since the 1920s suggests that krill abundance has decreased and the abundance of salps increased. Although krill have been commercially fished since the mid-1970s, the catches are relatively small compared with
estimates of standing-stocks so the authors suggested the observed changes were more linked with environment and predation pressure.

For short-lived species (Tables 1 to 4) overall stock abundance is strongly influenced by the strength of the incoming year-class and this in turn is determined both by the amount of eggs produced (spawning stock effect) and their subsequent survival. Short-lived species are also particularly susceptible to runs of poor recruitment because there is relatively little buffering capacity (spread of age classes) in the adult stock {the age spread is often severely reduced by exploitation even for longer-lived species (Longhurst 2002), (Hsieh et al. 2006)}. Environmental sensitivity is often evoked as an explanation for the large inter-annual changes in catches seen in short-lived SPF, such as the Peruvian anchovy (Table 1, Figure 3). In these cases attention often focuses firstly on sea temperature which affects multiple processes through all life-stages of fish (Peck et al. 2013). Examples for SPF include effects on metabolic rate (Bernreuther et al. 2013), oxygen uptake (Pörtner and Farrell 2008), growth and feeding (Arrhenius and Hansson 1994, Baumann et al. 2006a), spatial movements (Corten 2001, Rose 2005b) and maturation and spawning (Winters and Wheeler 1996, Takasuka et al. 2005). The availability of oxygen may be particularly relevant to shoaling SPF as respiratory demands have been shown to structure schools (Domenici et al. 2002, Brierley and Cox 2010) and to lead to reduced seawater oxygen concentrations in fjords containing large shoals of over-wintering herring (Dommasnes et al. 1994). However, sea temperature is often correlated with other environmental variables which may have as much influence. For example, wind-stress is known to exert control over up-welling and ocean mixing and thus influences primary production and will also generate turbulence which affects encounter rates between larval fish and their prey. These mechanisms are particularly relevant in the coastal up-welling zones where many of the major stocks of SPF occur (Cury and Roy 1989).

Because of their life-history characteristics, Rose (2005b) suggested that SPF such as capelin (M. villosus) and herring (C. harengus) respond more rapidly to environmental changes compared with other ground-fish. This view was also echoed by Alheit et al. (2014). Life-history theory suggests that the responses to changes in the environment will involve trade-offs between different processes and that this can be used as a basis for exploring possible responses of SPF to climate change (Freitas et al. 2010, Baumann and Conover 2011). However, because of the complexity of environment-organism interactions it has proven difficult to pin-down specific life-stages where environmental controls on survival are exerted most strongly, although the egg to early juvenile stages often seem particularalry sensitive (Smith et al. 1992, Butler et al. 1993, Payne et al. 2009). Because of the importance of the strong inter-annual variability in recruitment for many SPF stocks, relations between environmental conditions and early life stages has received much more attention compared with the impacts of the environment on later stages (Hammann et al. 1988). A considerable amount of research has thus focussed on attempting to explain how recruitment success is driven by oceanographic conditions (Baumann et al. 2006b, Alheit et al. 2014). The ultimate hope of some of these studies was that relatively simple indices of environmental conditions
might be used to predict the strength of the incoming year-class. Thus attempts have been made to predict recruitment of S. African anchovy (*E. capensis*) from environmentally driven rule-based models (Bloomer *et al.* 1994, Daskalov *et al.* 2003). While such models have proven extremely useful for exploring hypotheses they have generally proven to have rather weak predictive power (Deyle *et al.* 2013). Part of the problem may be that models based on linear responses struggle to capture hysteresis-type ecosystem responses (Fauchald 2010). Application of non-linear techniques (Deyle *et al.* 2013) may prove more successful although I am not aware of any systems where this has been sufficiently tested within a management framework. Evidence also suggests that conditions affecting larval growth and survival in upwelling zones are highly variable over relatively small spatial scales and whether this can be captured with simple regional environmental indices remains debateable (Planque *et al.* 2004, Reum *et al.* 2011). To try and understand this spatial and temporal complexity, a number of coupled oceanographic-biological models have been developed incorporating SPF and often focussing on the early life stages (Bernsten *et al.* 1994, Mullon *et al.* 2002, Mullon *et al.* 2003, Parada *et al.* 2003, Miller *et al.* 2006, Brochier *et al.* 2008, Christensen *et al.* 2008, Huse and Ellingsen 2008, Dorman *et al.* 2011, Parada *et al.* 2012, Soto-Mendoza *et al.* 2012, Koné *et al.* 2013). Individual-based models have also been used to examine interactions between SPF and their predators (Huse *et al.* 2004). Such models have proven extremely useful for examining the impact of oceanography on processes such as egg and larval transport, growth and survival but, despite considerable progress, they do not yet seem to have sufficient predictive power to be particularly helpful in forecasting (Fréon *et al.* 2005, Cury *et al.* 2008, Stock *et al.* 2011).

It has been hypothesised that outbursts in SPF productivity are largely generated when survival rates of the early life stages of the fish improve resulting in a run of strong year-classes and that long-term shifts in the mean year-class strength are driven by factors linked to the coupled ocean-atmospheric system (Maccall 1996, Klyashtorin 1998, Lehodey *et al.* 2006). The apparent presence of multi-decadal cycles in SPF catch data led Klyashtorin (2001) to suggest that these are linked to the Atmospheric Circulation Index (ACI) and that this could be used to predict SPF yields out to 2050. There are a number of problems with this approach. Firstly for many stocks we only have time series long enough to observe one or two of these cycles. Paleo-records such as the Santa-Barbara scale-deposition data suggest low-frequency cycling with periodicities of up to 40-50 years (Holmgren-Urba and Baumgartner 1993, Yasuda *et al.* 1999, Hollowed *et al.* 2001, Fréon *et al.* 2008); secondly, the relationships between driver and response are based on correlations - the mechanisms underlying the relationships remain uncertain although, as previously mentioned, changes in sea temperature and wind-stress may be important (Yasuda *et al.* 1999, Takasuka *et al.* 2007, Takasuka *et al.* 2008, Jacobson and McClatchie 2013). Although one could use such predictions in management planning without understanding the mechanisms this is rather a risky approach and one most managers are probably reluctant to take (Walters and Martell 2004a). However, the results presented in Klyashtorin (2001) appear sufficiently compelling that the predictions made at that time should be compared with stock changes which will be observed over the next few decades. If stock yields can really be predicted over multi-decadal
timescales this could be a useful tool for better fisheries investment planning which tends to operate across similar multi-decadal timeframes (Fréon et al. 2008).

Alternatively one might use observations and short-term predictions of near-future environment conditions to inform management about incoming year-class strength (Stige et al. 2013). However, one will only gain useful advance warning if the environmental signal itself can be predicted with sufficient skill; in most cases this has still not proven possible (Planque et al. 2003, Reum et al. 2011, Barnston et al. 2012, Guemas et al. 2012, Oldenborgh et al. 2012) although see MacKenzie and Köster (2004). For some systems with very strong forcing, for example the Peruvian up-welling, observational programs have aided management, at least in providing some advance warning and explanation for changes in productivity but other researchers have questioned whether the benefits have been equitably spread across all affected sectors (Pfaff et al. 1999, Broad et al. 2002). Fréon et al. (2008) outlined the basic bio-economic management problem in SPF stocks in upwelling zones using Peruvian anchoveta as an example. During periods of high productivity strong investment allows fishing and processing capacity to build but the pay-back time on these investments tends to be longer than the fisheries productivity cycling interval. When the stock enters a lower productivity phase there is a significant lag in disinvestment so that the presence of the excess capacity leads to the stock being over-exploited increasing the danger of collapse, as happened in the early 1970s. An additional problem is that commodity prices also respond to supply (and to forecasts if available) so that as the stock enters a lower productivity phase, fishmeal prices increase. These price increases can sustain the excess capacity for a time increasing the risk of further damage to the stock but also making the industry operate in an economically inefficient manner. Price increases can also exclude local consumers, particularly the cash-poor sections of the society, from accessing the SPF resource.

Another example which seems to show rather strong cycles in abundance is the Norwegian capelin, Mallotus villosus (Petitgas et al. 2010). Declines in spawning stock biomass appear predictable several years in advance as a result of declines in recruitment (Rose 2005a) and the strength of the oscillations may be reinforced by dynamic interactions with the main predators of capelin, cod (G. morhua) and herring (C. harengus). Despite much progress in understanding such foodweb interactions, confidence in medium-term, multi-species stock projections remains low (Overland et al. 2010, Brander et al. 2013, Yatsu et al. 2013). Several authors have thus considered that present approaches to fisheries management, involving mostly short- to medium-term adjustments of allowable fish catches and effort, are likely to remain the main management tools, at least for the foreseeable future (Brander 2007, Dickey-Collas et al. 2013). Adjusting fishing effort for species which show strong inter-annual dynamics remains a challenge although Polovina (2005) discussed optimal harvest strategies for such stocks. Some of the results were encouraging in that optimal harvest for S. American pilchard (S. sagax) could be obtained even if changes in fishing pressure lagged shifts in ocean productivity by several years. However, species such as pilchard are relatively long-lived compared with other SPF (Table 1) and this longevity appears to allow some buffering in the system. Management of fisheries for shorter lived SPF, such as anchovies,
sprat and sandeels will likely have to continue to be largely reactive taking account of inter-
annual variability in recruitment, but also taking account of the wider ecosystem impacts of
the fisheries.

Compared with uncertainties regarding inter-annual and multi-decadal cycles, there is
more confidence in the projected long-term trends in global average climate. This is mainly
because of the strength of the underlying anthropogenic forcing (Oldenborgh et al. 2012).
Trends from climate simulations have been incorporated into a number of models to explore
the possible impacts on SPF yields of medium to long-term climate change (Hollowed et al.
2008, Merino et al. 2010, Yatsu et al. 2013). Despite this higher confidence, such projections
must still be treated cautiously because regional down-scaling and prediction of the frequency
of severe events, such as El Niños, have not yet been fully and successfully incorporated into
global climate models (Brander 2007, Foreman and Yamanaka 2011). It is also difficult to be
very prescriptive about what will happen to foodwebs under climate change as they may react
in un-predictable ways (Rudstam et al. 1994, Watters et al. 2003, Oguz and Gilbert 2007,
Norris et al. 2013). Nevertheless, these medium to long-term simulations may prove useful in
provoking discussion about the ways in which the industry and fishery-based economies will
need to adapt to changing conditions over the coming decades (Fox and Aldridge 2008,
Allison et al. 2009).

Models require data and there are several multi-disciplinary environmental
monitoring programs operating in major SPF areas e.g. the Pacific Coast Ocean Observing
System (details at www.pacoos.org). These programs aim to provide the observations of the
oceanography and biological communities in order to further investigate, among other things,
the linkages between ocean physics and the productivity of the fisheries. Continued funding
for long-term observational programs in the ocean is vital since, without these data, models
cannot be refined further nor model predictions tested against outcomes.
4. Overview of the use of SPF

SPF catches are utilised by humans both directly and indirectly. Direct uses include consumption of fresh, dried and canned products and production of pharma-nutrients. Indirect uses include feeding to livestock and conversion into fishmeal and oils (Alder et al. 2008, De Silva and Turchini 2008, FAO 2012). Although many of these products have been produced for thousands of years, others have emerged as new markets and preservation technologies have evolved. Over time there has been a considerable shift from direct human consumption of SPF to conversion into fishmeal and fish-oil. In recent years, Alder et al. (2008) suggest that around 90% of SPF landings were processed for meal and oil leaving around 1.7 Mt y⁻¹ for other uses. Whilst obtaining sufficient daily protein remains a key issue for many people in under-developed nations (Tacon and Metian 2009b, Tacon et al. 2009), in developed and emerging economies there is increasing demand for “high-value” fish which are often farmed higher trophic-level carnivores which require fishmeal and fish-oils in their diet. There is also increasing emphasis on the dietary aspects of human health and fish oils in particular have been widely promoted as having benefits for cardiovascular, skeletal and mental health (Akter et al. 2012, Greene et al. 2013). For example, in the United Kingdom the Department of Health recommends adults eat at least two portion of fish per week, one of which should be an oily type e.g. sardines or mackerel. However, direct consumption of fresh oily fish, such as herring and sardines, often seems to decrease as societies become wealthier (Delgado et al. 2003, Alder et al. 2008). Diet survey data can be somewhat misleading in this regard since increased consumption of oily-fish in the UK in recent years seems to be mainly a result of increased sales of farmed salmon (Henderson and Gregory 2002, Bates et al. 2011). Given some consumers reluctance to consume fresh fish, purified high-strength omega-3 oils have been heavily promoted as health supplements and are often sold in capsule form (Shepherd and Jackson 2013). Although much of the fish-oils used are derived from non-SPF species, species such as menhaden and Antarctic krill are also utilised. As well as concerns about over-blown claims regarding the health benefits of fish-oils, Greene et al. (2013) raised the issue of a general lack of awareness in public health agencies about the limits on supplies of wild fish. If increasing numbers of people follow public health recommendations to consume more oily fish (Dewailly and Rouja 2009) this could put significant additional pressure on wild SPF stocks (Fox 2010).

4.1. Use of SPF as food by humans

Compared with the ecological aspects of SPF there seems much less information available on the degree to which SPF are used directly for human consumption. There have been several reports on the nutritional value of SPF (van Pelt et al. 1997, Payne et al. 1999) and they are generally regarded as a good source of protein and long-chain polyunsaturated fatty acids for both humans and other animals (Alder et al. 2008, Thilsted 2012, Roe et al. 2013). SPF protein often has a high content of lysine and other essential amino acids making these species a valuable complement to carbohydrate-rich diets consumed in places where other protein sources are limited. SPF are also rich in micronutrients such as potassium, iron, phosphorus and vitamins A and D (Sánchez Durand and Gallo Seminario 2009). The proximate composition of the fish does however vary with location and season, particularly in
regard to the lipid and moisture content (De Silva et al. 2011). Because of the n-3HUFA content in particular public health guidelines in the UK recommend that at least one portion of oily fish be consumed per week, although oily fish includes salmon (Scientific Advisory Committee on Nutrition 2004). Marine SPF can be particularly important as a source of nutrition for cash-poor coastal communities operating small-scale fisheries (Kawarazuka 2010, Thilsted 2012).

Prior to the 1930s most SPF catch was used for direct human consumption but preventing spoilage of lipid-rich fish had always been problematic. In the north-east Atlantic the traditional methods of preservation were curing with salt or smoking and this was mainly applied to Atlantic herring (Clupea harengus). In the Mediterranean, salting of anchovies and sardines also had a long history with numerous accounts of this activity from ancient Rome (Kurlansky 2003). In warmer countries sun-drying of SPF is feasible and is still practiced today. At the end of the 1800s alternate methods were developed which offered significant advantages over salt preservation. Freezing began to be applied but mainly to non-SPF species as it did not work well with the oil-rich SPF. However, canning was more successful resulting in a product which could be easily transported and stored without loss of nutritional value. Off California canning of sardines (S. sagax) began in the early 1900s and by 1925 had become a significant industry on the US west coast. However, there was also increasing demand from agriculture for cheap sources of protein for poultry feeds and for direct use as fertiliser and reduction of sardines for meal also began to increase. Concerns about the non-food use of the sardine were raised as early as 1920 when state rules were passed favouring the use of whole fish for canning. However, this acted as a perverse incentive as the canneries began selling canned product at cost simply in order to obtain enough waste for reduction. Around the 1930s several floating reduction factories were anchored outside of state waters to get around these rules. By World War II around 0.5 Mt of sardine were being landed per annum despite warnings from fisheries scientists that this was un-sustainable. By this time most money was to be made from fish oil rather than the canned product. Landings began to decline rapidly after 1952 and the last fishing season was in 1968 (Ueber and MacCall 1992). In 1974 a moratorium was imposed which halted directed commercial fishing but also eliminated catches for bait (although an incidental by-catch was allowed). In the 1980s the stock began to increase although it never reached the biomass levels estimated for the 1930s. In 1986 the moratorium on commercial sardine fishing in California was lifted and landings peaked in 2007 but have since declined (California Department of Fish and Wildlife 2013). After the sardine fisheries collapsed there was a sharp increase in use of anchovies for canning which reached 39 Kt in 1952. Catches of anchovy declined after 1959 to around 1.2 Kt. This may not have reflected a strong stock decline since when permits in 1966 were issued for a renewed anchovy reduction fishery, catches increased rapidly (Lucas 1986). During the 20th century the general story-line of the California sardine fishery has been seen several times, in particular the early focus on use of SPF for human consumption, followed by the development of industrial uses leading to over-investment in catching and processing capacity, environmental change leading to reduced productivity followed by collapse of the fishery. The fisheries for herring (C. harengus) in the North Sea and anchoveta (E. ringens) off Peru have largely followed this path.
In Peru canning began during the Second World War and expanded rapidly in the 1950s. The main species used were bonito (*Sarda chilensis*) and Pacific menhaden (*Ethmidium maculatum*). The canning industry then went into decline as fishmeal production took over but the industry resurged in the 1980s focussing on sardine (*S. sagax*). This boom did not last long as catches of sardine collapsed in the early 1990s (Figure 22) creating a new crisis for the canning sector. Presently the industry relies mainly on jack and chub mackerel but also processes some anchovy. Direct human consumption of anchoveta has increased from 10.6 Kt in 2001 to 42.3 Kt in 2006 and the amounts used for canning and curing have also risen from 3.3 and 5.7 to 31.0 and 10.7 Kt respectively. Despite this increase the total non-fishmeal use of anchoveta only accounts for around 0.8% of total anchoveta landings (Sánchez Durand and Gallo Seminario 2009).

Chilean SPF fisheries followed similar catch trends to Peru (Figure 24) being largely driven by the same oceanic forcing (Section 3.5). Annual per capita consumption of fish in Chile is relatively low (around 7 kg per person) and most of the landings are processed for meal and oil. About half Chilean total fish production comes from industrial catches but there is a significant artisanal sector (responsible for 32% of production). Around 432 Kt of frozen fish products were produced in 2005, up from just under 200 Kt in 1995, of which around 50% was cultivated Atlantic salmon and rainbow trout and 35% pelagic based. The majority of the pelagic based product was from medium-sized species such as jack mackerel, anchoveta and sardines only contributed around 1%. There has also been a slight increase in production of fresh (chilled) fish for human consumption but output of preserved products has been rather static over the period 1995-2005. Again the majority of chilled product has come from the farmed sector. Canned products are also produced but at a lower level (109 Kt in 2005).

This pattern of conflict between industrial and human consumption use does not apply to all SPF, for example capelin (*Mallotus villosus*) and sandeels (*Ammodytidae*) have never been consumed directly by humans and in these cases the potential impacts of the industrial fisheries on other parts of the marine foodweb (Table 12) are the cause for concern.

In many developing countries, SPF remain an important source of protein and lipid for direct human use. An analysis of global use of SPF for human consumption was undertaken by Tacon and Metian (2009b). They estimated that the proportion of total catch destined for reduction to meal or oil has been relatively stable since the mid-1980s in line with findings in this report (Figures 33 & 34). In contrast the proportion destined for use in farm-made feeds, petfoods or for bait has been increasing from 0.9 Mt in 1970 to 13.1 Mt in 2006 (Tacon and Metian 2009a). A proportion of this non-food use comes from non-SPF species but Tacon and Metian (2009b) pointed out there was a strong correlation between reported landings of SPF and the trend in estimated fishmeal production (Figure 33). Global per capita fish supply has increased to around 18.8 kg per person in 2011 but an increasing proportion of this is coming from aquaculture (Table 13). The demands from aquaculture for fishmeal and oil are discussed further in Section 4.2.2. Geographical analysis of the importance of SPF for human consumption shows strong regional patterns. Pelagic fish form a particularly high proportion (> 40%) of total fish consumed in Africa, Europe, Latin
America and the Caribbean and sub-Saharan Africa (Tacon and Metian 2009b). For several countries in Africa including Gambia, Guinea and Sierra Leone fish are especially important with fish contributing >50% of animal protein supply. Overall it was estimated SPF contribute > 50% of total fish supply in 36 countries. Most of these countries are in Africa but also include Sri Lanka, Yemen, Albania, Maldives, Kasakhstan, Honduras, El Salvador, Togo, Ukraine, Ecuador, Romania, Turkey, Vanuatu, Panama, Philippines, Malta, New Caledonia, French Polynesia, Samoa, Trinidad and Tobago. Of total SPF landings, around 17% ended up being traded as food-grade processed products. The main species involved include Atlantic herring, anchovies and pilchards (Tacon and Metian 2009b) also included mackerels in their review with imports into many African countries, especially Nigeria being important. Other significant importers include the Russian Federation, Ghana, Netherlands, Korean Republic, Japan, China. Europe was also the top producer of processed products made from SPF. Exports of food-grade SPF from Peru have declined strongly, but from Chile have increased (although again most of this is mackerels not included in the present review). For Namibia and S. Africa anchovy attracts lower prices compared with horse mackerel so is usually reduced for meal. In Namibia pilchard is valuable and the majority is canned with waste being used for meal and oil production. Most of the canned product is exported to S. Africa or Europe. The channelling of fish products to export markets can clearly deprive local populations of this source of nutrition. In Asia demand for SPF for direct consumption or conversion to fish sauce must compete with increasing demands for use as fresh aquaculture feed or for conversion into meal (De Silva and Turchini 2009). This is of concern because the price which can be paid is usually higher from the farm sector compared with direct consumers (Edwards et al. 2004).

Traditional techniques for preserving SPF are widely used in countries such as the Philippines with small pelagics being brine-salted and then dried and larger fish split, salted and dried. However, a wide range of processed food-grade products can now be produced from SPF including surimi (Park 2013). In Greece SPF are processed by salting, drying, smoking and canning but, according to Bentis et al. (2005), fish too small for processing are often discarded. To utilise these under-sized fish they trialled whether S. pilchardus could be used for surimi production. Results were generally positive but product quality varied with the proximate composition of the raw material which in turn varied with location and timing of catch (De Silva et al. 2011). Recent studies have also investigated whether it is possible to fortify surimi derived from pollack (Theragra chalcogramma) with (n-3)PUFAs derived from SPF such as menhaden or krill (Pietrowski et al. 2011). The aim here would be to increase nutritional intake of long-chain PUFAs for human health benefit via a product (surimi) which already has widespread market acceptance.

SPF are also targeted for their roe with the main fisheries being on Atlantic (Clupea harengus) and Pacific (Clupea pallasi) herring (Spratt 1992, Bledsoe et al. 2003). There are good markets for products derived from herring roe in Japan. The herring row fisheries are among some of the shortest in the world e.g. the fishery in Sitka Sound, Alaska may only operate for one or two days each spawning season. Some of the roe is also harvested using the “roe-on-kelp” method which does not kill the adult herring. Production of roe-based
products has fluctuated significantly since 1976 (Figure 31). Very low reported values since 2007 are probably artefacts of delayed reporting and should be ignored. Overall production increased up to 1995 but has since fallen driven by declining production by Japan since when the U.S.A and Canada have increased. Herring represent a very small portion of total Japanese SPF landings (Figure 23) and while landings were relatively high (> 50 Kt) in the early 1970s, they fell sharply after 1975 generally being < 20 Kt. During the 1970s Japan began importing large quantities of roe from the USA (Spratt 1992). The general correspondence between the decline in production of roe-related products since 1995 and overall global landings of herring (Figure 32) is not very convincing although reported landings of Pacific herring (*Clupea pallasi*) have declined a little over this time. Recruitment success of Pacific herring is thought to be affected by temperature but the links are not strong and no mechanisms have been identified (Beamish 2008).

Figure 31: Trends in reported roe production from herring – 1976 – 2009. The sum of weights for products made by different methods (curing, drying, frozen) is shown, data have not been corrected back to original wet weights.
The main obstacles to increasing availability of SPF for human consumption are economic. In addition, (Tacon and Metian 2009b) suggested that the emphasis from conservation has been on sustainable stock management without much attention being paid to how the resource is partitioned between end-users. In many countries most of the SPF catch is moved directly to processing plants and so does not have a chance of entering the local human consumption food-chain. This practice, whilst being economically efficient, may be in conflict with aims of the FAO Code of Conduct for Responsible Fisheries, one article of which states that priority should be given to meeting the nutritional needs of local communities. Although these issues have been widely publicised in the media and presented in rather simplified terms, closer analysis suggests a more complex situation with the impacts of the fish-trade on cash-poor sections of society being positive, negative or neutral depending on location (Hecht and Jones 2009, Wijkström 2009, Béné et al. 2010). There have been some legal initiatives aimed at protecting at least a segment of the SPF landings for direct human use. The early state legislation in California has already been described at the start of this section although it seemed to back-fire and led to the development of offshore processing as a mean of circumventing the rules. Other examples are in Peru where larger SPF such as Jack and Chub mackerel and sardine cannot be used for reduction {Decreto Supremo N8 001-2002-PRODUCE cited in Tacon and Metian (2009b)}. As discussed in the next section demand for SPF is likely to increase in the coming decades. It is therefore up to the governments and societies of nations with SPF stocks in their waters to decide how to use their resource for the maximum benefit to their citizens and to enact and implement appropriate legislation (Tacon and Metian 2009b). However, developed nations such as those in the European Union, must be held to account in setting fair reciprocal fisheries agreements with less developed countries (Bretherton and Vogler 2008, Swartz et al. 2010).
Table 13: Global fisheries production and consumption from 2006-2011 (FAO 2012)

<table>
<thead>
<tr>
<th>Year</th>
<th>Capture fisheries (Mt)</th>
<th>Aquaculture (Mt)</th>
<th>Total (Mt)</th>
<th>Direct consumption (Mt)</th>
<th>Non-food use (Mt)</th>
<th>Non-food use relative to capture landings (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2006</td>
<td>90.0</td>
<td>47.3</td>
<td>137.3</td>
<td>114.3</td>
<td>23.0</td>
<td>25.6</td>
</tr>
<tr>
<td>2007</td>
<td>90.3</td>
<td>49.9</td>
<td>140.2</td>
<td>117.3</td>
<td>23.0</td>
<td>25.6</td>
</tr>
<tr>
<td>2008</td>
<td>89.7</td>
<td>52.9</td>
<td>142.6</td>
<td>119.7</td>
<td>22.9</td>
<td>25.6</td>
</tr>
<tr>
<td>2009</td>
<td>89.6</td>
<td>55.7</td>
<td>145.3</td>
<td>123.6</td>
<td>21.8</td>
<td>24.4</td>
</tr>
<tr>
<td>2010</td>
<td>88.6</td>
<td>59.9</td>
<td>148.5</td>
<td>128.3</td>
<td>20.2</td>
<td>22.6</td>
</tr>
<tr>
<td>2011</td>
<td>90.4</td>
<td>63.6</td>
<td>154.0</td>
<td>130.8</td>
<td>23.2</td>
<td>25.6</td>
</tr>
</tbody>
</table>

A number of human health issues have also been raised in relation to direct consumption of SPF. Many lipid soluble organic pollutants (e.g. PCBs, dioxins, toxaphene and dieldrin) can be found in SPF and this has led to recommendations that pregnant women should consume oily fish at lower levels than other segments of the population (Scientific Advisory Committee on Nutrition 2004). This represents a classic risk trade-off since eating oily fish is also thought to have significant benefits for the health of both expectant mothers and their offspring and a major concern of the committee was how this advice could be communicated to the public in a clear manner (Mahaffey et al. 2011). The recommendation of lower weekly intake based on the SACN report has subsequently been questioned and these arguments picked up by the UK media (Gray 2013). However, this is likely to lead to further public confusion regarding safe levels of SPF consumption. Because lipid soluble pollutants become concentrated up the food-chain there is even more concern when fish-meals and oils containing these substances are fed into aquaculture systems over extended periods of time and this aspect is discussed later on. It should also be noted that these concerns are separate from the issue of methylmercury which is present in larger pelagics such as tuna and swordfish (Mahaffey et al. 2011). Because of their filter-feeding habit, SPF such as menhaden may also potentially accumulate toxins from harmful algal blooms. Del Rio et al. (2010) reported the presence of potentially toxin (domoic acid) producing algae in the guts of Gulf menhaden (B. patronus) although domoic acid levels in fish tissues were low. The authors concluded that Gulf menhaden may act as a vector for transmission of DA within coastal foodwebs although there did not seem any immediate human-health risk. Parasites in the flesh of commercially fished SPF can also have implications for human health (Levsen et al. 2005).
4.2. Non-food uses of fresh SPF by humans

4.2.1. Use of SPF as bait and fresh-feed for aquaculture

SPF have been widely used by humans as bait-fish in many fisheries. In the 1960s, northern anchovy (E. mordax) was reported to contribute 98% of the total live bait used in California (Lucas 1986). In the US east coast around 50 to 75 Kt annum\(^{-1}\) of Atlantic herring (C. harengus) or around 70% of the US Atlantic herring catch is used as lobster bait (Lehuta et al. 2013). In this case the amounts of bait used may be so large as to act as a bioenergetic subsidy to the shellfish, nutritional inputs which may in part explain the substantial expansion of the lobster stock in some localities (Grabowski et al. 2010). Other species commonly used as bait in other fisheries include menhaden (small amounts used as bait for the Gulf Coast blue crab fishery), mackerel and sardines (Tacon 2009). Herring is also widely used in the north-east Atlantic for baiting *Nephrops* creels (Mason et al. 2002).

In the Pacific and Indian Oceans, small pelagics such as *Stolephorus*, *Thryssa*, *Sardinella*, *Dussunieria*, *Spratelloides* and *Rastrelliger* spp., *Exocoetidae* and *Hemiramphidae* are exploited in both artisanal fisheries and for live bait for pole-and-line tuna fishing (Dalzell and Lewis 1989). Increased consumer demand for more sustainably caught tuna followed high-profile campaigns regarding cetacean by-catch in purse-seine fisheries. Pole-and-line tuna fishing is now well established with the main producer countries being Japan, the Maldives and Indonesia. The Japanese operations are distant-water vessels whilst other countries tend to fish more locally (IPNLF 2012). As a fishing method pole-and-line has been encouraged by conservation campaigners such as Greenpeace because of low by-catch rates (Clydesdale 2012) but concerns have been raised about the need for baitfish. According to the account cited around 1 kg of baitfish is used for every 10 kg of tuna landed although Gillett (2011) suggested a ratio as low as 1:32. Achieved ratios are highly variable with geographic region, fishing technique and bait species (IPNLF 2012). It is important to have as accurate estimates of these ratios as possible since they have been used to estimate the total baitfish requirements for this fisheries sector (by raising the data on the total tuna captures by rod-and-pole). While the by-catch benefits and support for local export economies of pole-and-line fishing appear well evidenced (Gillett 2011), there is less information on whether the use of live bait-fish in this manner is sustainable. In the Pacific the bait-fisheries tend to be adjacent to coral reefs, although not on the reefs themselves. SPF are attracted at night using submersible lamps and then captured using dip-nets, small purse-seines or lift nets (Dalzell and Lewis 1989). The Japanese operations are much more industrialised with separate bait-catching operations which sell live bait to the tuna vessels. The bait is “hardened” in sea-pens to improve its subsequent survival in captivity. The bait is then kept live in seawater wells in the tuna fishing vessels for up to several months during fishing operations (IPNLF 2012). There have been a few studies on mortality rates during the “hardening” stage but estimates seem highly variable depending on bait species, capture method, stocking density and handling. Dalzell and Lewis (1989) also commented on the availability of data at the time and noted that although some timeseries of catch records had been collected, estimates of effort were lacking. They also noted the problem that SPF stocks may rarely be at equilibrium being subject to perturbation by environmental fluctuations,
such as monsoon intensity. This means it is difficult to fit simple stock models, such as surplus production, which can sometimes be used with catch only timeseries. Such models are generally not recommended due to their poor track record, especially when applied to small pelagic species such as Peruvian anchoveta (Laws 1997, Aranda 2009). Alternative approaches have been to try and link SPF baitfish yields to estimates of primary production. There also seems to be strong geographic variations in SPF productivity such that atolls are less productive than high (volcanic) islands, this feature appears to be driven by the levels of freshwater run-off which are presumed to affect nutrient availability in the near-shore region. However, excessive precipitation reduces salinity and increases turbidity and has a negative effect on some SPF species (refs. cited in Dalzell and Lewis (1989). The pole-and-line fisheries must also compete with industrial purse-seine operations outside of countries EEZs. Operation costs for smaller-scale pole-and-line fishers are a major problem in terms of competing with the industrial purse-seiners and Japanese pole-and-line fleet so that concepts which add cost, such as large-scale bait-transport, are unlikely to be particularly useful to the sector (Gillett 2011). More recently the amounts of live-bait required by pole-and-line fisheries have been estimated at between 19 and 48 Kt annum\(^1\) (IPNLF 2012). That report highlighted several issues around baitfish use including potential food-web impacts and noted that there is a distinct lack of research, data and models of trophic interactions of reef associated small-pelagics compared with the amount of research for temperate marine ecosystems (Smith \textit{et al.} 2011). Social aspects of the baitfish-tuna sector were also considered including competition for resource with artisanal fisheries and social problems arising from migratory fisheries. Governance capacity of the Pacific countries in particular in regard to design and implementation of practical fisheries management plans has also been questioned (Gillett 2011). The overall conclusions are that there is a need for both more research and for more technical support for managers and local communities with regard to developments in this sector.

In terms of global marine aquaculture finfish production yellowtail (\textit{Seriola quinqueradiata}) rearing in Japan and Korea ranks third after Atlantic salmon (\textit{Salmo salar}) and rainbow trout (\textit{Onchorynchus mykiss}). In 2011, 1.7 Mt of Atlantic salmon, 290 Kt of trout and 146 Kt of yellowtail\(^{11}\) were reared (FAO FishStat). Other \textit{Seriola} species are also cultivated but not to the same extent as \textit{S. quinqueradiata} (Nakada 2008). Unlike salmon and trout rearing, yellowtail production is not a closed system as it relies on juvenile fish being caught at sea and transferred into cages for rearing. Initially yellowtail rearing relied on locally available trash fish for feed but the industry developed strongly in the 1980s as a result of the availability of abundant cheap SPF, mainly Japanese sardine (\textit{S. sagax}). It was discovered that yellowtail could be fed on frozen sardine which was either minced or chopped and government support led to numerous freezing plants being set up along the coast. Yellowtail have a high dietary lipid requirement (> 20% by weight) a large proportion of which must be (n-3)PUFA but the lipid content of the sardines varies seasonally which led to nutritional problems and research into formulated feeds. With the drastic decline in the

\(^{11}\) Note that FAO FishStat uses “Japanese amberjack” for \textit{Seriola quinqueradiata} whereas Nakada \textit{Nakada M.} 2008. \textit{Capture-based aquaculture of yellowtail}, FAO No. Rome calls this species “yellowtail” and “amberjack” is used for \textit{Seriola dumerili}. In FAO FishStat, \textit{Seriola dumerili} is called “Greater amberjack”.
sardine catches in the early 1990s (Figure 23) attention focussed on developing alternate feeds and pellets became increasingly accepted. Nevertheless in 2004 yellowtail aquaculture still used 0.9 Mt of fresh fish (being a mix of sardines, horse mackerel, mackerel and sand-lance), in addition to 49 Kt of powder and 148 Kt of pellets. The main reason is that in the third year of the production cycle it is difficult to attain the required dietary intake using pellets so use of fresh fish is preferred (Nakada 2008).

As well as being used for bait in tuna fisheries, there is increasing demand for small fish for fattening and farming tuna (Ottolenghi 2008). As with yellowtail, small-sized tuna are caught at sea and transferred to large sea-pens where they are on-grown. “Fattening” occurs over short periods (3-7 months) whilst “farming” can be up to 2 years. The aim is to smooth fluctuations in availability, to rebuild muscle fat lost in gonad development and, when performed over longer periods, to rear fish to the minimum size for the lucrative Japanese fresh tuna market. The practice has become established both in the Mediterranean, Mexican Pacific and Australia (Alder and Pauly 2006). Developments in the Mediterranean have been reviewed by Mylonas et al. (2010). Tuna farming is practiced only in Croatia but fattening is undertaken by Cyprus, Greece, Italy, Malta, Spain, Tunisia and Turkey. The tuna are fed lipid rich species including SPF such as sardinella (Sardinella aurita), pilchard (Sardina pilchardus), herring (Clupea harengus), medium-sized pelagics such as mackerel (Scomber scombrus), horse mackerel (Trachurus spp.) and chub mackerel (Scomber japonicus) and sea-bream (Boops boops) and cephalopods. There do not seem to be any reliable estimates of the amounts of SPF used in this sector in the Mediterranean. There are possibly social benefits from the industry if it can be put on a long-term sustainable basis. Ottolenghi (2008) estimated that the tuna fattening sector provided between 1,000 and 2,000 jobs in the Mediterranean area although they also noted conflicts with other fisheries sectors and users of the coastal zone.

In Mexico, S. Americam pilchard (S. sagax) landings in 2006 were in excess of 0.5 Mt and most was destined for meal production and some for canning. However, Tacon and Metian (2009b) reported that the development of tuna fattening resulted in prices for freshly caught pilchard increasing from around $70 t\(^{-1}\) to as high as $300 t\(^{-1}\). Competition was such that fishmeal factories were finding it hard to source raw material. It was estimated that tuna fattening was using 50-70 Kt compared with 94 Kt for direct human consumption (prepared, canned or frozen) and 80 Kt for fishmeal (although this also contains other sources). Fattened tuna was the second most valuable aquaculture crop in Mexico after shrimp. The long-term sustainability of tuna ranching in the region is heavily dependent upon availability of fresh S. sagax for feed. However, both the spatial distribution and abundance of this species is strongly affected by oceanic conditions making the tuna fattening industry vulnerable to environmental disruption (Lehodey et al. 2006). For a fuller examination of tuna fattening in the Baja region see Zertuche-González et al. (2008).

Tuna fattening began in Australia where the target is southern blue-fin (Thunnus maccoyii). In 2003, 5 409 tonnes of wild-caught tuna (average weight 15 to 30 kg) were fattened to 9 102 tonnes over a period of three to five months, fed solely on pilchard and mackerel. The approximate increase of 4,000 t to fattened weight required 50 to 60 Kt of imported trash
Small fish as fresh feed, also widespread in Asia (Naylor and Burke 2005). The term “trash fish” is often used but this is rather imprecise and can be applied to any fish with low market value due to their size, quality or lack of demand (Funge-Smith et al. 2005). Trash fish tend to come from incidental catches (by-catch or non-target catch) and SPF are likely to form a component in many warm-water fisheries, particularly those operating inshore using fine-mesh nets. SPF are less likely to be significant by-catch components in offshore demersal-trawl fisheries because of their position in the water column (Ulleweit et al. 2010). By-catch may either be discarded at sea or landed along with the more valuable components of the catch. Small to medium sized pelagic species, such as Rastrelliger, may be discarded in some round-fish fisheries due to their lower market value while catches of under-sized and over-quota SPF may be “slipped” in some mid-water and purse-seine pelagic fisheries. Although “slipping” refers to releasing fish from the nets before they are hauled on-board, crowding of the fish in the nets probably leads to a large mortality in the slipped fraction, although this has not been well quantified (Stratoudakis and Marçalo 2002). Seine fisheries catch the vast majority of small pelagics globally and they are estimated to contribute around 350 Kt (or around 5%) to the total global discards estimated at 7.3 Mt (Kelleher 2005). In large parts of Asia nearly all the by-catch will be landed as there is a market for its use as fresh feed for aquaculture (De Silva and Turchini 2009). In Bangladesh and India a greater proportion is directly consumed and less fed to other animals (Funge-Smith et al. 2005). There have been several attempts at estimating the quantities involved but these are usually restricted to single-country studies (Edwards et al. 2004). In addition, because of the wide and variable species mix in trash-fish landings, figures are usually not recorded to species level and it is impossible to quantify the amounts of SPF in these catches (De Silva and Turchini 2009). According to Funge-Smith et al. (2005) the increasing demand for trash fish has led to an increase in the numbers of small vessels fishing in inshore waters. That study also assumed that the species being caught were short-lived and highly productive and that while there was little evidence of over-exploitation they did caution that little was known about the ecosystem impacts of these fisheries in potentially fragile inshore areas. A further issue is poor-handling of catches which can effectively reduce them to trash-fish status. In Vietnam up to 60% of higher-value trawled catch may be spoiled in this manner (Funge-Smith et al. 2005).
4.2.2. Use of SPF for the production of fishmeals and fish oils

The majority of SPF caught globally are now used for the production of fishmeal and fish-oils rather than directly consumed by humans. Global production trends are recorded in the FAO Fishstat database. The International Fishmeal and Fish Oil Organisation (IFFO) holds its own data which were analysed by Shepherd and Jackson (2013). Although the overall trends between the two datasets are in agreement, the IFFO data suggest lower levels of fishmeal production compared with the FAO data. The IFFO estimate for fishmeal and fishoil production for China in 2009 was only 160 Kt whereas FAO estimated 1.4 Mt (Shepherd and Jackson 2013). The FAO data have been used in the following analysis because they are publically available and will give a more cautionary estimate on the total amount of fresh SPF used for reduction compared with the IFFO data.

SPF contribute the bulk of the raw material for meal and oil production although offcuts from farmed fish are also being increasingly used (Alder et al. 2008). The species used can be categorised into industrial-grade forage (Gulf B. patronus and Atlantic menhaden B. tyrannus, sandeel Ammodytes spp. and capelin Mallotus mallotus); food-grade forage (anchovies E. ringens, E. japonicus, E. encrasicolus, European sprat Sprattus sprattus) and prime food-fish (herring Clupea spp., European sardine Sardina pilchardus, S. American pilchard Sardinops sagax). Other species excluded from this review but which may be included in the FAO “Fishmeals nei” category include various mackerels (Trachurus/Scamber spp.) and blue whiting (Micromesistius poutassou). Although FishStat does allow the recording of the source of fishmeal to species level, most is reported simply as “Fish meals nei” so it is difficult to split total production to source (Tacon and Metian 2009a). In addition, production levels by many countries have had to be estimated by FAO officials because of a lack of properly reported statistics. There is thus considerable uncertainty about both the source, and quantities of fishmeal being produced.

According to FishStat, 187 Mt of fishmeal were produced globally between 1976 and 2009, of which only about 2-3% was reclaimed from fish waste (this percentage has been increasing in recent years). It is generally estimated that it takes 5 kg of fresh fish to produce 1 kg of meal (Delgado et al. 2003, De Silva et al. 2011) so global fishmeal production would have required 910 Mt of fresh fish. This quantity of fresh fish exceeds total SPF landings in the same period by 165 Mt (Figure 33). The reason for this discrepancy is probably that around 20% fishmeal has been produced from species not included in the present review (Péron et al. 2010). For example, data in Bórquez and Hernández (2009) suggests that 27% of meal production in Chile in 2005 came from Jack mackerel and 15% from unidentified “trash fish”. Use of “trash fish” as an aquaculture feed (either live or locally converted into meal) is particularly widespread in Asia and will include a wide range of species including SPF such as Sardinellas and Dussumierids (De Silva and Turchini 2009). Landings records for “trash fish” are almost entirely based on estimates and may represent a significant source of under-

12The following sources were included in this figure: Anchoveta meal; Capelin meal; Clupeoid fish meal, nei; Fish meal fit for human consumption, nei; Fish meal obtained from fish waste; Fish meals, nei; Herring meal; Jack mackerel meal; Mackerel meal; Menhaden meal; Pilchard meal; Sandeel meal and Sardine meal. Specific records for Blue whiting meal and other non-SPF sources were excluded.
reporting. Another problem is that there is a discrepancy between species listed in accounts considering fishmeal production using the term “forage fish” (Alder et al. 2008) and the species included as “small-pelagics” in the present report. Species used to produce fishmeal (and so contributing to the “Fishmeal nei” category) but not included in the present report include Jack mackerels, blue whiting, haddock, Norway pout, pollack and miscellaneous trash fish (Alder et al. 2008, Péron et al. 2010). Although this may explain some of the apparent short-fall in raw material for fishmeal (Figure 33), it is difficult to analyse this further without better recording of the sources from which the meal has been produced (Deutsch et al. 2007, Tacon and Metian 2009a, Péron et al. 2010). This is an important point since such discrepancies can highlight problems of misreporting (Watson and Pauly 2001, Pauly and Froese 2012).

![Figure 33: Trends in total SPF landings and fishmeal and fishoil production](image)

The overall trend in global fishmeal production closely follows the trend in total SPF landings (Figure 33), which in turn is largely driven by changes in the catches of anchoveta (Figures 1 and 3). Current levels of fishmeal production are fluctuating around the 5.5 Mt level (Figure 34). Consideration of the main species used for large-scale industrial fishmeal production largely explains the rank order of fishmeal producing countries, the top two
producers being Peru and Chile (Table 14 and Figure 34). Production by countries outside the top ten individual producers has remained relatively stable since 1976 at between 0.5 and 1 Mt y\(^{-1}\); the Soviet Union was an important producer up until 1992; production from Thailand has increased slightly over time but production by Japan has decreased significantly; in contrast production by China has increased from virtually zero in 1981 to a present level of 1.4 Mt y\(^{-1}\).

**Figure 34: Global production of fishmeal by country**

The trends in landings of SPF over time for Peru and Chile have already been described (Figures 22 and 24) with the dominant species landed being anchoveta and S. American pilchard. Fishmeal production by Peru in recent years has fluctuated around the 1.3 Mt. level but due to stronger management, fish catches by Peru are expected to decline further in 2013 to about 5 Mt., so fishmeal production will also likely decline to around 1 Mt. Fishmeal production by Chile has decreased compared with the mid-1990s. Chile also began to use increasing amounts of other species, such as jack and chub mackerel, for meal production from the mid-2000s (Bórquez and Hernández 2009). Fishmeal production by Chile is currently around 0.5 Mt y\(^{-1}\). Japan has overall been the third largest producer of fishmeal (1976-2009). Landings of SPF species by Japan have been more diverse compared with Peru and nearly all species may have contributed to meal production to some extent (Figure 23). China ranks fourth in terms of meal production but was not a traditionally significant producer. Chinese reported SPF landings have also increased rapidly since 1990 (Figure 35). After allowing for use of reclaimed fish (20%), and taking a ratio of 5:1 fresh fish:fishmeal (Delgado *et al.* 2003, De Silva *et al.* 2011), the amount of fresh fish required to produce this amount of meal (~50 Mt) still significantly exceeds the total reported Chinese SPF landings of around 18 Mt (over the period 1976 to 2010). As with other countries this suggests substantial other sources are being used for fishmeal production (Péron *et al.* 2010). This requires further investigation since there are known to be significant problems with the accuracy of Chinese fisheries data (Pauly and Froese 2012, Pauly *et al.* 2013).
Figure 35: Reported SPF landings by China

Most SPF landings by Denmark (ranked fifth in producer countries) were of sandeels and capelin, although historically herring were more important (Figure 36). The majority of the sandeel and capelin landings have been used for meal and oil production. Again SPF landings do not appear sufficient to supply the amount of fresh fish required to generate this amount of fishmeal although the discrepancy is not so large as for some other countries (55 Mt required compared with reported SPF landings of ~34 Mt, 1976-2009).

Figure 36: Reported SPF landings by Denmark

Fishmeal is used in a wide-range of products from foods for direct human consumption, pet foods (De Silva and Turchini 2008) but principally for aquaculture feeds. The reduction of fresh fish to meal has been widely criticized, principally because of the metabolic losses which occur when it is fed to other reared carnivorous species (Naylor et al. 2000, Naylor and Burke 2005). There would clearly be energetic advantages if a greater proportion of SPF
landings were directly consumed by humans but it seems doubtful that the trend of increasing demand for higher-trophic level species, such as salmon, seabass and shrimp, can be reversed. In addition not all SPF species are suitable for direct human consumption, for example sandeels, and their use in an aquaculture food-chain may be no less efficient than allowing them to remain in the natural food-web (Huntingdon 2009). Increased direct consumption of SPF by humans would also generate nutritional benefits (Thilsted 2012), particularly compared to consumption of higher trophic level fish in tropical areas (Dewailly and Rouja 2009). Fox (2010) however cautioned that this recommendation largely ignored the existing pressures on low-trophic level species. Considerable amounts of SPF are also used for production of feeds for pets and fur-animals (Figure 37). De Silva et al. (2008) estimated that around 13.8% of global “forage fish” catch was used in this manner (note that their estimate of global catch of “forage fish” in 2002 was 39 Mt, considerably higher than the estimate of 23.4 Mt for total SPF landings in this report for the same year).

Tacon (2009a) collated estimates from a number of sources on the use of fishmeal and the data clearly show a major shift from utilisation in poultry to aquaculture feeds (Figure 37). The rising demand for feedstuffs for aquaculture has been considered in a recent FAO Technical Report (Tacon et al. 2011).

Figure 37: Changes in the relative uses of fishmeal between 1988 and 2008. Modified from data in Table 1 of Tacon (2009a). The proportions shown for 2002 are broadly in line with estimates of global forage fish use given in De Silva et al. (2008) for that year.
Table 14: Global fishmeal (dry weight) production during the period 1976 to 2009

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Total 187,486,449
Farming fish and shellfish generally requires an external source of nutrition (the exceptions are shellfish such as clams, oysters and mussels which can be grown entirely using natural food sources). Artificially added nutrition can be in the form of fresh feed, or farm-produced or industrially produced pellets. Input feeds are normally designed to provide all the protein, lipids, carbohydrates, fibre and micronutrients required (although in semi-intensive systems environmental food sources, sometimes encouraged by pond fertilisation, can provide at least some of these components (Southgate 2012)), ensuring good growth rates, healthy stock and a commercially acceptable final product. Fishmeal is included primarily as a source of protein because its amino-acid profile should be close to that of the reared animals. However, the proportion of fishmeal which must be included in the feed varies considerably with the species being reared. For example, carps and tilapias grow well on diets with low levels (around 1-3%) but salmon diets require 12% or more (Naylor et al. 2009). Over time the proportion of fishmeal in diets for all reared species has been successfully reduced as terrestrial products, such as soy-meal and corn-meal, have been increasingly used (Trushenski and Gause 2013). These changes can be seen by comparing data from 1995 and 2010. In 1995 total aquaculture production reliant on external feeds (i.e. excluding groups such as plants, clams, mussels and oysters) was about 4 Mt and this required a total of 7.6 Mt of feed-input of which 1.9 Mt was fish-meal (Tacon et al. 2011). For the fishmeal component the consumption-to-production ratio was thus around 0.5. By 2010, total fed aquaculture production had risen to about 21 Mt and required just over 35 Mt of feed, of which 3.7 Mt was fishmeal. This gives a fishmeal consumption-to-production ratio of 0.2, clearly demonstrating the levels of fishmeal sparing now achieved. The principal driver behind attempts at replacement has been concern over volatility of supply which is partly reflected in fishmeal prices. The ratio of the unit price of fishmeal to soymeal remained relatively constant between 1981 and 1997 at around 2.4 but then increased rapidly in response to a strong fall in the catches of anchoveta reaching 4.5 in 1999 (Delgado et al. 2003). The price ratio then fell back slightly following something of a recovery in anchoveta landings but in 2006, the price of fishmeal increased strongly to over US$1500 t⁻¹ and has remained above US$1100 t⁻¹. However, the price of soybean meal has also been increasing so that the present (August 2013) ratio of fishmeal to soymeal prices is around 4. There is thus continued pressure on feed manufacturers to find cheaper alternatives to fish meal since feed costs represent a major expense in fed aquaculture systems (Hardy 2010, FAO 2012). Given these trends, Tacon et al. (2011) suggested that overall demand for fishmeal for use in aquaculture up to 2020 would decrease slightly (Figure 38). However, these levels still represent a significant fraction of overall fishmeal production. In 2010, an estimated 3.7 Mt of fishmeal were used in aquaculture feeds i.e. about 70% of the total global production of 5.3 Mt in that year (Tacon et al. 2011). Assuming a ratio of 1:5 fishmeal:wet weight and that 20% of fishmeal was produced from fish waste, this would have required about 14.8 Mt of fresh fish, or 88% of total reported SPF landings (16.8 Mt). The proportion of total fishmeal production sourced from fish waste has also increased over time and in 2009 was around 21% although only China appears to be reporting this in the FAO database. A higher estimate of 36% reclaimed meal is quoted in FAO (2012) although the source of this estimate is unattributed.
In contrast to reductions in the proportion of fishmeal in aquaculture feeds, there has been less success in replacing marine fish-oils and demand, particularly for use in aquaculture feeds, continues to grow (Figure 39). Whilst many important species, such as carps and tilapias, grow well on diets lacking marine fish-oils, many other species currently being cultivated, or being considered for cultivation, do not (Naylor and Burke 2005). Species such as Atlantic salmon (*Salmo salar*), European seabass (*Dicentrarchus labrax*) are higher-trophic level predators and lack the enzymes necessary for elongating and de-saturating shorter-chain fatty acids (Bell and Koppe 2011). Long-chain polyunsaturated fatty acids (LC-PUFAs) are thus essential dietary components for these species but feed containing low to moderate amounts of fishmeal can often supply adequate amounts of EFA (Turchini *et al.* 2009). With increased used of vegetable-based meals, the (n-3):(n-6) FA ratio becomes more important (Sargent *et al.* 1999) and paradoxically the need to supplement diets with fish-oil might actually increase as proportions of fishmeal are reduced. As with fishmeal, there has been considerable research into reducing and replacing marine-derived oils in aquaculture feeds (Naylor *et al.* 2009, Turchini *et al.* 2009, Turchini *et al.* 2011) and these efforts have achieved some success. Overall levels of fish oils in salmon pellets have been reduced from around 40% in 1990s to 22% and could be reduced even further (Tacon *et al.* 2011). There is also increasing sophistication in feed composition which can be tailored to the stage in the production cycle so that grow-out diets, with reduced levels of fish-oils, can be used for much of the rearing cycle and animals are only transferred onto a high-lipid “finisher” diet before harvest. Although these approaches can reduce fish-oil use across the whole production cycle,
there remain problems with effectively altering established fatty-acid profiles in the fish tissues to deliver a product the market finds acceptable (Glencross and Turchini 2011). Despite these trends for reduction and replacement, marine oils remain essential for the production of high-value species, particularly salmon and marine shrimp, and demand is increasing at such a rate that the overall use of marine lipids aquaculture is expected to continue to rise (Figure 39).

With the exception of some specialised oils for use as pharma-nutrients, fish oils are generally derived as a by-product of fishmeal manufacture (Olsen et al. 2011). It is therefore no surprise that there is a close correspondence between trends in the global production of fishmeal and fish-oil (Figure 33). Between 1976 and 2009 FAO data suggest that 39.5 Mt of fish-oil have been produced (Table 15). The majority of this is recorded as “Fish body oils, nei”. Other sources are recorded to species level e.g. anchoveta oil, but this varies with country e.g. Chile recorded all its fish-oil production in the mixed species category, even though most probably came from anchoveta or S. American pilchard (Figure 24). Because of this analyses below have been based on total fish-oil production. Rates for oil yield vary with species and water temperature and can be as low as 1% of wet weight up to 10%, the average ratio of fresh fish to oil yield is often taken to be around 20:1 (De Silva et al. 2011) and this value has been applied in Figure 33. Global production of fish-oil from 1976 to 2009 will have therefore required around 790 Mt of fresh fish. This is lower than the estimated amount of fresh fish needed for fishmeal production during this period (910 Mt) but a little higher that the total declared SPF landings of 745 Mt. As with fishmeal, other non-SPF sources, such as fish livers, are likely to be included in the “Fish body oils nei” category.

![Global Fish-oil production by country](image)

**Figure 40: Global production of fish-oil by country**

Globally fish-oil production has been declining since the mid-1980s and is presently fluctuating around 1 million tonnes (Figure 40). In terms of producing nations, rather fewer countries have recorded fish-oil production compared with fishmeal. The rank order of the
top fish-oil producing countries also differs slightly (Table 15). In recent years Peru has produced around one-third of global output at 350 Kt y⁻¹ but this is expected to decline to around 300 Kt in 2013 due to further cuts in anchoveta quota as fisheries management is tightened. As with fishmeal, total production of fish-oils by countries outside of the top-ten has been relatively steady (Figure 40). Both Morocco and China began recording production in the mid-1980s and the quantities produced have increased slightly over time. Production by South Africa fluctuated between 20 and 40 Kt up until 1990 but appears to have declined to very low levels since then. The timing of this decline coincides with a strong reduction in landings of S. African anchovy (Figure 41). Fish-oil production by Iceland and Denmark has remained relatively stable apart from a few periods of reduced output but production by Norway has decreased significantly since the late 1970s. This seems to be linked to the switch in Norwegian SPF landings from capelin, which dominated catches between 1970 and 1985, to herring (Figure 25). Fish-oil production by the United States of America has declined slightly since the mid-1990s whilst Chilean production expanded in the mid-1990s but has since declined to around 165 Kt in 2009. Production by Japan has changed dramatically across the time-series, from 1976 to around 1990 it was one of the largest single nation producers but since then output has fallen to less than 65 Kt. This can be directly attributed to the collapse of the fishery for Japanese pilchard (Figure 23).

Figure 41: Reported SPF landings (S. Africa) – 1950 - 2011
Table 15: Global fish-oil production during the period 1976 to 2009

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<th>Rank</th>
<th>Country</th>
<th>Production (tonnes)</th>
<th>Rank</th>
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</tbody>
</table>

In 1995, aquaculture production reliant on external feed inputs used 463 Kt of fish-oil in feeds (Tacon et al. 2011). This gave a consumption-to-production ratio of around 0.11. By 2010 global fed production used 764 Kt of oil to produce around 21 Mt of product (total wet weight) so that the consumption-to-production ratio had fallen to 0.03. This was achieved mainly by improvements in the formulation of salmon and trout diets where excessive oil levels had previously led to fish health and quality problems. Despite these improvements, the overall demand for fish-oil is predicted to increase. This is mainly driven by increasing production of marine fishes such as Japanese and European seabass (Lateolabrax japonicus and Dicentrarchus labrax), flathead grey mullet (Mugil cephalus), gilthead seabream (Sparus aurata) and Japanese yellowtail (Seriola quinqueradiata) (Figure 39). There has been a substantial shift in fish-oil use from mainly human consumption (about 69% of total production in the 1990s) to aquaculture (87% of total production in 2006).
4.3. Health issues associated with human consumption and use in aquaculture of SPF

Because many organic pollutants are lipid soluble (e.g. PCBs, dioxins, toxaphene and dieldrin) they can become concentrated up the food-chain particularly when fishmeal based pellets are used for extended periods (Hites et al. 2004, Olsen et al. 2011). There is also evidence that farm-sites can become sources of organic contamination to wild, such as saithe (Pollachius virens) and cod, which ingest excess pellets (Bustnes et al. 2010). There has been significant negative publicity generated by this issue with concerns about the effects of consumption of both reared fish and fish-oil supplements on the unborn child being prominent. However, the issue is complex and dose calculations suggest there may actually be less exposure from taking oil supplements compared with eating an equivalent FA-delivery of wild fish (Ashley et al. 2010). Producers should minimise contaminants in their products by careful choice of the source of the raw materials (Suominen et al. 2011) and by using modern decontamination methods (Maes et al. 2005, Kawashima et al. 2009, Usydyus et al. 2009, Lock et al. 2011). There should also be regular testing and publishing of analysis results from both raw materials and processed product (Suominen et al. 2011). Guidelines and standards for sourcing and production have been set by the International Fishmeal and Fish Oil Organisation (IFFO) and many major fisheries and producers are now certified against this standard (see IFFO website for details). However, quality control becomes logistically more challenging in countries such as China which operate large numbers of small fishmeal processing plants. As with other costly feedstuffs there have also been problems with deliberate adulteration i.e. adding cheaper components to bulk out the meal and thus increase profits. Modern forensic methods are perfectly able to detect even trace levels of contamination in fish-meals (Nagase et al. 2009, Doosti et al. 2011) so quality control is now more dependent upon having rigorous logistical systems for testing in place. Recent problems in Europe with contamination of processed meat products demonstrate that, even for advanced economies, the logistics of quality control in complex food manufacturing chains remains a major challenge (van Vark et al. 2013).

4.4. Future trends in demand to SPF

The price of fishmeal and fishoils is affected by demand versus supply and the pricing of alternate protein and lipid sources such as soy (Shepherd and Jackson 2013). If the price of fishmeal increases, relative to alternatives such as soy, economic theory predicts that consumers will tend to reduce their demand for the higher cost product. This pattern does seem to have occurred with regard to the proportions of fishmeal used in aquaculture feeds (see Section 4.2.2). Fluctuations in the relative fish/soymeal price ratio were examined in more detail by Asche et al. (2013). Their analysis suggests that the price has two regimes, a relatively stable state seen during parts of the 1990s and a high price regime as seen during short-periods in the 1990s and from around 2003 onwards. Whilst levels of direct human consumption of some SPF species, for example sand-eels, menhaden (and Norway pout and blue whiting) are negligible, other important SPF (anchovies, sardines etc.) are used both for direct consumption and production of fishmeal (see earlier in this section). Demand for SPF for direct consumption has been increasing, although for S. American anchoveta not at a
substantial rate. In some cases periods of increase in the fish/soy price ratio appeared to be triggered by El Niño events e.g. during 1997/98. However, the ratio fell back after relatively quickly until 2002-03 when another El Niño occurred. Since then subsequent El Niños in 2006-07 and 2009-10 appear to have triggered further increases, but during this period the mean price ratio did not return to the levels observed during most of the 1990s i.e. the high average price regime has persisted. The price is also affected to some extent by forecasts of future El Niño timing so that the ratio begins to increase a few months prior to some events. Asche et al. (2013) do not really explain why, despite decreasing proportions of fishmeal in aquaculture feeds, prices have remained so high but they, and others, suggest this is linked to increased demand from China (Shepherd and Jackson 2013). Despite many of the species principally cultivated, such as carps and tilapia, having little essential requirement for fishmeal in their diet most farmers in China use pellets containing at least some fishmeal (Chiu et al. 2013). Despite low levels of fishmeal in tilapia and carp pelleted feeds (1-3%), the scale of cultivation by Chinese aquaculture appears to be driving increasing world competition for fishmeal. Overall there has also been a slight decline in global meal production since the mid 1990s (Figure 33). Shepherd and Jackson (2013) ascribe this mainly to stricter fisheries management, particularly in the main anchoveta fishery, but also to reduced productivity from fisheries in the South China Sea and Gulf of Thailand due to overfishing. Although Asche et al. (2013) concluded that the fishmeal price flips between two regimes (adequate supply: relatively low price; inadequate supply: high price) they did not speculate on whether we may now be stuck in a high-competition, high-price regime (Naylor et al. 2009, Tveten and Tveten 2010).

Demand for fish-oils has followed a slightly different trajectory to that for meal. As described in section 4.2.2 marine oils remain essential components in formulated feeds for many species of reared marine fish, such as Atlantic salmon (S. salar), even though the proportions used have been reduced significantly (Naylor and Burke 2005, Naylor et al. 2009, De Silva et al. 2011). Prices for crude fish oil have risen and stayed high in recent years. Prices paid for crude oils for the production of human nutritional supplements tend to be even higher as this sector demands raw materials with high-quality (specific fatty acid profiles) and low levels of contaminants (Schultz 2012). Other potential sources of (n-3)PUFA rich lipids, such as GMO crops and microalgae, are in development but probably will not make a substantial contribution to global production for at least five years (Shepherd and Jackson 2013). In some parts of the world, particularly Europe, there is also substantial public resistance to use of GMO products in the human food-chain although this position may shift over time (Durrant and Legge Jr. 2005). Alternate sources of marine lipids such as Antarctic krill are being exploited but mainly for the high-end health supplements market. Further expansion of these fisheries would likely be met with substantial public opposition due to concerns about knock-on effects of these fisheries within Antarctic food-webs. It has been suggested that eliminating discards within the European capture fisheries could help meet some of the additional demand for fish oils (Shane 2013). However, how the proposed EU ban will actually function and the amounts of additional useable raw material it might generate remain to be seen (Mangi and Catchpole 2012).
As demonstrated in earlier sections of this report, catches of many of the more important SPF are prone to large inter-annual variability. This is particularly true for species in the Pacific which are affected by El Niño events (Shepherd and Jackson 2013). Although El Niños occur approximately every 3-5 years it has not proven feasible to predict them with long lead times (Barnston et al. 1999, Ding et al. 2012). This is somewhat surprising given results shown in Chen et al. (2004) where they claimed ability to hind-cast the timing and strength of El Niños over the last 148 y with lead times of up to 2 y. Their conclusion was that El Niños are controlled more by self-sustaining internal dynamics than stochastic atmospheric forcing. However, Barnston et al. (2012) reviewed the performance of recent coupled ocean-atmosphere models and concluded that although there had been a slight improvement, forecasts made more than about 4-6 months prior to the event generally had very little predictive skill. There is clearly a need for concensus to be reached on El Niño forecast ability since reliable forecasts could be of significant benefit to managing the SPF stocks affected by this phenomenon. However, even given reliable forecasts there may be considerable variations in the degree to which this information can be accessed by different sectors of society (Orlove et al. 2004). It is likely that forecasts will be more readily accessed and acted upon by the industrial fisheries and this could further disadvantage small-scale human use sectors. The industrial fisheries are likely to have the resources to respond to forecasts through measures such as stock-piling of raw materials whilst these options are rarely available to small-scale fishers (Pfaff et al. 1999, Broad et al. 2002). However, forecasts of the 1997/98 El Niño may have been useful to small-scale fishers in terms of protecting their houses, boats and fishing gear (Orlove et al. 2004). Forecasts of El Niño appear to have had more success in relation to terrestrial agricultural management although problems of regional down-scaling and effective communication of probabilistic information remain (Goddard et al. 2010). Fishmeal and fishoil availability thus show similar volatility to other agricultural sector products where realised production is strongly affected by largely unpredictable weather and climate events (Tothova 2010).

Because of this unpredictable nature of weather, predicting short-term fluctuations in future price trends in agricultural commodities is always hard (Tothova 2010). However, prices are also affected by longer-term trends and the general pattern of increasing demand for SPF derived products seems a reasonable assumption based on a range of factors including: estimates of human population growth (United Nations 2012); increasing urbanization in coastal mega-cities (Sekovski et al. 2012); increasing levels of disposable income in some developing countries (Delgado et al. 2003); shifts in consumer preference from “low-status” to “high-status” marine foods mainly of which will be farmed (Naylor and Burke 2005); increasing demand for marine-based health food supplements (Shepherd and Jackson 2013). The only factor which might reduce demand dramatically would be a significant breakthrough in finding alternative, cheaper substitutes for fishmeal and fishoil for use in aquafeeds (Miller et al. 2011). Based on global fisheries consumption trends during the 1990s, Delgado et al. (2003) projected future demand for fisheries products out to 2020. In particular they were concerned with addressing questions such as whether cash-poor consumers would be crowded out of the market. The study suggested five main conclusions:-
Developing countries, particularly in Asia, would come to dominate aquaculture and capture fisheries production. The remaining quarter of fisheries not already fully-exploited, which are mainly in the tropics, would become more heavily fished.

The source of net fisheries exports would shift from north to south with south-south trade becoming increasingly important.

More effective management would spread through fisheries with particular focus on reduction fisheries due to their foodweb importance.

Continued efforts to reduce use of fishmeal and oil in aquaculture feeds would be made.

Institutional development, particularly in developing countries would become recognised as a necessary condition for poverty reduction through fisheries development. Ecolabelling and sustainability certification would become increasingly important and demanded by consumers.

Now that we are over half-way towards 2020 from the year that report was published it is clear that most of these predictions with relevance to SPF are happening. In particular we have seen the rise of China’s importance as both a producer and consumer of SPF and related products; there is some evidence of more effective management spreading through the major SPF fisheries e.g. development and implementation of stricter management plans for Peruvian anchoveta; efforts to reduce use of fishmeal and fishoil in aqua-feeds are showing some results (section 4.2.2) although the rates of reduction are not enough to reverse increasing overall demand, and several major SPF fisheries are now subjected to sustainability audits and certification (see section 5.4).

Although there have been many reports which describe the patterns of global trade in SPF products there are fewer bio-economic models available for exploring the effects of changes in productivity on supply and price. Mullon et al. (2009) presented one such model of the producer-consumer economic linkages for SPF at a global-scale. Although production by the fish stocks was represented by simple surplus-production models i.e. ignoring the impacts of short-term events such as El Niños, the model could be used to explore a number of scenarios including changes in climate, fuel prices, demand and sudden falls in production caused by events such as El Niños. Perhaps the most important finding was that there was a threshold of increased demand beyond which the system was less able to recover from severe shock events. This is probably because the model predicts increasing prices at low supply levels which, if demand is sufficient, drives excess fishing pressure which prevents rebuilding of the main Peruvian anchoveta stock. The implementation of effective harvest control rules allowed better resistance of the model system to such shocks by preventing collapse of the anchoveta stock and thus maintained global SPF supply in the longer-term. These conclusions are similar to those reached by Fréon et al. (2008) who modelled how lags between decadel-productivity and investment-disinvestment cycles causes problems within the Peruvian anchoveta fisheries.

The research discussed in this section leads to a number of conclusions:-
In the short- to medium-term:-

- More effective fisheries management of the major SPF stocks should maintain harvest levels at around present levels although there may be further decline as more effective catch controls are more widely applied.
- Increasing incorporation of results from food-web modelling into management plans should result in tighter catch controls during times of reduced SPF productivity in order to minimise fishery impacts on other components of the food-web and maximise chances of stock rebuilding.
- SPF yields from the major anchoveta stocks will continue to be subject to largely unpredictable short-term fluctuations linked with El Niño events but improved management should prevent the stock collapsing during these events as long as over-capacity can be controlled.
- Increased pressure on SPF for use as food for humans or for feeding to other animals could result in decreased yields and some collapses for less well-managed SPF stocks.
- Fisheries exploitation of the few remaining SPF stocks currently assessed as being under-exploited will increase and robust management plans need to be developed urgently for these stocks in anticipation of this.
- Continued high demand for SPF will generate resource competition and keep prices high. This will make it increasingly difficult for cash-poor consumers in coastal-megacities to afford SPF for consumption.
- The major Peruvian anchoveta stock may enter a lower productivity period, if this happens and excess fishing capacity is not removed more quickly than in the past, another period of over-exploitation could result with negative consequences for global SPF supply.

In the longer-term:-

- Significant reductions in demand for SPF for aquaculture feeds may be achieved which would free up more SPF resource for other uses. However, new sources of aquafeeds will need to also be suitable for rearing of emerging carnivorous marine species in cultivation.
- Climate change may lead to reductions in the productivity of the major SPF stocks in up-welling zones but productivity of SPF stocks in high latitudes may increase.
5. Issues associated with small pelagic fisheries

5.1. Increasing demand for SPF and possible alternatives

Because the supply of “forage fish” clearly represents a limiting resource there have been numerous attempts to find alternative sources for fishmeal and fish-oils (Muller-Feuga 2000, Naylor et al. 2009, Turchini et al. 2009). Some of these attempts have been based on terrestrial crops or microalgae (Muller-Feuga 2000) but others have examined alternative marine sources (Miller et al. 2011, Olsen et al. 2011). The use of terrestrial alternatives is outside the scope of the present review but there have been numerous trials to test the effect of replacing fish with meal from krill, amphipods and copepods (Moren et al. 2007, Suontama et al. 2007). Most trials have shown that these sources are comparable to fishmeal in terms of achieved growth and feed conversion rates but some health issues have arisen related to fluoride accumulation. The severity of this problem appears to vary with the rearing environment, species being reared and other dietary components in the feed (Moren et al. 2007, Yoshitomi and Nagano 2012). However, most of the fluoride can be removed through processing since it is found predominantly in the exoskeleton of krill and amphipods (Yoshitomi et al. 2007, Yoshitomi and Nagano 2012). Krill also appears to contain powerful feeding attractants but these compounds are often lost during conventional processing (Tibbetts et al. 2011). Although freeze-drying preserves these active compounds the process costs will probably limit its widespread uptake as a replacement for conventional fishmeal.

Although both northern and southern krill have been explored as potential sources of fishmeal they have recently attracted more attention as a source of oil for use in pharma-nutrients (and also as sources of chitin and chitosan which are of medical interest). A major problem is that krill degrade rapidly after capture but modern processing methods using “suction harvesting” have overcome this (Tarling et al. 2010). In the 1990s several experimental fisheries were conducted for the northern krill, Meganyctiphanes norvegica. This boreal species is found over shelf-slope regions and in deeper parts of the shelf seas. It is found throughout the north Atlantic, as far south as the Bay of Biscay (occasional records from the western Mediterranean) and Cape Hatteras, but principally in the more northern waters of the Irminger and Norwegian Seas. It is less common in the open Atlantic (Tarling et al. 2010). In 1991, the Maritime Region of Department for Fisheries and Oceans Canada issued a permit for zooplankton harvesting and experimental fishing began in the Gulf of St. Lawrence. Only 6.3 t of krill and 0.4 t of copepods were caught, considerably less than the permitted total allowable catch (TAC). In 1995, TACs were increased but reported catches were only 2 and 1 t respectively (krill and copepods). There has apparently been little interest inreviving the fishery since (Tarling et al. 2010). In the north-eastern Atlantic very small amounts of northern krill (and copepods) are permitted to be harvested by Norway (Figure 25) and this seems unlikely to be increased due to environmental concerns (Olsen et al. 2011). Also northern krill generally occur in less dense swarms compared with Antarctic krill and this also explains why commercial fisheries have failed to develop for this species (Tarling et al. 2010).
In Pacific waters, Nicol (1997) and Nicol and Endo (1999) reported that three species were being commercially exploited: *Euphausia pacifica; E. nana* and *Thysanoessa inermis* with *E. pacifica* or “Isada” being the most important. The fishery in 1987 appears to have been largely local using a form of bow-trawl. Such methods may have been used for over 100 years. The fishery was controlled by a system of local licencing. Since then use of twin-boat seines has become more common and with increasing demands for feed for sea-bream cultivation, and for use as bait for sport fishing, the fishery expanded to the north and south of Miyagi province. The total annual catch apparently increased from around 40 Kt to 100 Kt by 1992. The present status of this fishery does not appear to be recorded. In the US Pacific there have been substantial regulatory changes regarding krill fisheries. The Pacific Fishery Management Council voluntarily adopted Amendment 12 in 2006 which banned fishing for krill in the EEZ west coast waters and in 2009 this was formalized at federal level by NOAA (National Oceanic and Atmospheric Administration). Krill are still harvested further north in British Columbia where they are used as bait for sport fishing, or as raw material for aquaculture feed. The B.C. fishery has a 500 t annual limit which has not been increased since 1975 (Nicol and Endo 1999) and in 2011, reported landings had fallen to just 150 t and only four vessels were taking part (Fisheries and Oceans Canada 2013f). Despite these accounts there are no catch data in FishStat for *E. pacifica* which suggests under-reporting, even though this catches are likely at a rather low level for this species.

In contrast the fishery for Antarctic krill (*E. superba*) has become firmly established since the first experimental attempts in the 1970s (Figures 14 and 20). Although yields peaked at nearly 500 Kt, current catches are lower at around 250 Kt y⁻¹. However, the number of countries involved has increased over time with vessels registered in the Russian Federation, Poland, Norway, the Republic of Korea, Japan and recently Chile and China taking part. Landings by China in particular have increased rapidly despite the logistical problems of operating such a distant-water fishery (Chi et al. 2013). The location of the fishery has thrown up several conflicts. Krill play key roles in Antarctic food-webs (see later in this report) and this has led to widespread objections to any commercial harvest. The distant location of the fishery also means that much more fuel is used in obtaining krill products compared with other sources of marine fish-oils (Parker and Tyedmers 2012). On the other hand much of the marketing of Antarctic krill-based oils relies on the fact that they are harvested from a remote environment widely regarded as being one of the last “clean” places on the planet (Mercola).

Exploratory fishing from the mid-1980s to 1990s suggested that yields of krill were much higher from the Atlantic compared with the Indian and Pacific sectors (Figure 14; Medley et al. 2009) and the SW Atlantic was estimated to hold around 50% of the total Southern Ocean krill biomass (Atkinson et al. 2004). Commercial krill fisheries have thus developed in the Atlantic sector but not in the Pacific and Indian (Figure 14). In 2010, the Marine Stewardship Council certified Aker Biomarine as operating a sustainable krill fishery (Medley et al. 2009). This decision was challenged but upheld at adjudication. Much of the argument for these fisheries being sustainable is based on estimates of the total biomass of krill in the Southern Ocean being around 60 Mt or more, so present harvest levels represent
only 0.4% of this figure. Fisheries for krill in the Southern Ocean are managed through CCAMLR (Commission for the Conservation of Antarctic Marine Living Resources) which will be discussed later in this report.

The importance of meso-pelagic and bathy-pelagic fish in the deep-sea has already been mentioned (Section 1). Globally the biomass of meso-pelagics has been estimated at around 1,000 Mt but this estimate may be too low due to sampler avoidance (Gjøsæter and Kawaguchi 1980) (Kaartvedt et al. 2012). Small-scale exploratory fisheries for myctophids (an important group within the mesopelagic fishes) operated off South Africa, in the sub-Antarctic and in the Gulf of Oman in the 1970s and early 80s but present catches are rather low (Catul et al. 2011, Olsen et al. 2011). The majority of the catches were used for fishmeal production although some species can be used directly for human consumption (Catul et al. 2011). Myctophids often have high oil and wax ester content and this caused problems with post-catch spoilage in the initial exploratory fisheries. However, with increasing demand for fish-oils this potential source may be re-examined (Olsen et al. 2011). The ecology of the myctophids is not particularly well understood but many are known to have low fecundity and this, coupled with their importance in marine food-webs (Moteki et al. 2001, Potier et al. 2007) and carbon cycling (Davison et al. 2013), would raise serious conservation concerns if significant fisheries were to develop (Catul et al. 2011). Commercial fisheries do target some of the bathy-pelagic species such as the Greater argentine (Argentina silus). This species is found between 180 to 550 m depth, has slow growth and can live for up to 35 y and is commercially fished in the northeastern Atlantic (Pierce et al. 2002). It has no value for direct human consumption and catches are converted into fishmeal.

Increasing volumes of fishmeal and fish oil are also likely to be derived from fisheries by-products. So far only China has reported the amount of fish meal reclaimed from fish waste but this has been rising steadily to reach 1.2 Mt in 2009. The proposed elimination of discarding in European Union capture fisheries could also increase the amount of material available for fishmeal and fishoil manufacture (Shane 2013). Although it is hoped this policy will encourage the development and use of more selective fishing gears (so reducing the total level of by-catch), new uses will probably have to be found for at least some the by-catch which cannot be avoided. Discards from the English and Welsh fleets have been estimated at 25 Kt y⁻¹ (Mangi and Catchpole 2012) whilst some global estimates are as high as 7.3 Mt y⁻¹ (Kelleher 2005). The main impediment to increased use of discards for fishmeal production in the UK appears to be the relatively low price which would be paid to fishers by processors (less than £150 t⁻¹) when compared with the higher prices which might be obtained by increasing direct human consumption of discards (Mangi and Catchpole 2012).

5.2. **Sustainability of SPF fisheries within an ecosystem-based approach**

5.2.1. **Introduction to the ecosystem-based approach to fisheries management (EAFM)**
The phrase 'Ecosystem approach' was first used in the early 1980s, but developed from international debates going back to the 1970s (FAO 2003). The term found formal acceptance at the Earth Summit in Rio in 1992 where it became an underpinning concept of the Convention on Biological Diversity. In 1995 FAO introduced the voluntary Code of Conduct for Responsible Fisheries (FAO 1995) which, although it does not use the words “Ecosystem-based approach” explicitly, includes a number of relevant clauses which are presented in abbreviated form below:

Clause 6.1: right to fish carries an obligation to do so in a responsible manner.

Clause 6.2: deals with sustainability of the resource and other components of the foodweb, both of which should be maintained “in sufficient quantities for present and future generations in the context of food security, poverty alleviation and sustainable development. Management measures should not only ensure the conservation of target species but also of species belonging to the same ecosystem or associated with or dependent upon the target species.”

Clause 6.3: states should prevent overfishing and build up of excess capacity. Depleted stocks should be rehabilitated (as far as possible).

Clause 6.4: management should be based on best available science evidence but also traditional knowledge, environmental, economic and social factors. Also mentions transboundary management.

Clause 6.8: critical habitats should be protected.

Clause 6.9: calls for integrated coastal management i.e. fisheries are taken into account in managing the multiple uses of the coastal zone.

This report has already described some of the catastrophic pelagic stock collapses which occurred during the 20th century, namely Pacific sardine, Peruvian anchovy and North Sea herring. Several of the clauses above are particularly relevant to improving management of similar stocks, namely: 6.2 and 6.3, 6.4 for stocks such as Pacific sardine which move across national boundaries and clause 6.8 for SPF with a strong inshore associations.

The Code also talks about the Precautionary principle:

“States should apply the precautionary approach widely to conservation, management and exploitation of living aquatic resources in order to protect them and preserve the aquatic environment. The absence of adequate scientific information should not be used as a reason for postponing or failing to take conservation and management measures.” (Clause 7.5.1)

We have also seen that many SPF stocks react rapidly to changes in environmental conditions and clause 7.5.5 is particularly relevant here:

“If a natural phenomenon has a significant adverse impact on the status of living aquatic resources, States should adopt conservation and management measures on an emergency basis to ensure that fishing activity does not exacerbate such adverse impact.”
The absolute need for effective legal and administrative frameworks to deliver effective management is also addressed in Sub-article 7.7.

Article 9 of the Code relates to aquaculture but does not explicitly mention issues of feed supply from the wild (Section 4 of this report). The closest relevant clause is 9.4.2 which says that states should:

“promote efforts which improve selection and use of appropriate feeds, feed additives and fertilizers, including manures.”

This aspect has been dealt with in more depth in 2010 in FAO Technical Guidelines for Aquaculture Development. Here the issue of use of small pelagics and/or trash fish for feed is specifically mentioned as a factor which should be taken into account (Section 2.3.4.1 in FAO (2010a).

The code reflects the move from open-access, un-managed fisheries to one where most fisheries lie within a state’s 200 mile exclusive economic zone (EEZ). Countries therefore have a responsibility under international law for managing their marine resources.

FAO laid out further guidance on the Ecosystem-Based Approach to Fisheries (EAFM) in 2003 (FAO 2003). The key points can be summarised as follows:

- EAFM is not a new concept and has developed along with the evolution of ideas regarding sustainability
- EAFM strives to balance diverse societal objectives by taking account of uncertainty
- EAFM merges ecosystem management, focused on protecting components of the ecosystem e.g. through use of marine protected areas (MPAs), with fisheries management.
- EAFM has sustainability at its core – present activities should not jeopardise the ability of future generations to derive the full range of goods and services provided by the ecosystem.
- EAFM needs to be delivered at appropriate spatial scales, functional management units should align with meaningful ecological boundaries.

The guidelines lay out a number of steps which would be followed:

- Identify the fishery, area and all relevant stakeholders;
- Identify broad social, economic and ecological (including the fisheries resource) issues for the fishery, based on the broad international and national policy goals and aspirations
- Set broad objectives for these issues
- Break down broad issues into issues specific enough to be addressed by an identified management measure(s)
- Rank the issues based on the risk they pose to the fishery
- Set agreed operational objectives for the high-priority social, economic and ecological issues identified and develop linked indicators and performance measures
• Formulate management decision rules
• Monitor the fishery using the selected indicators, and regularly evaluate the performance of management in meeting operational objectives – by inference, because of the linkages developed between policy goals and operational objectives, this will provide an assessment on how well management is achieving the broader policy goals

Again the precautionary principle comes into play as the guidance states that there will always be a lack of (full) knowledge concerning ecosystem functioning and structure,” but “uncertainty must not prevent the development of operational goals based on the best available knowledge.” The principles are as applicable to “data-poor fisheries with low scientific and management capacity” as to “fisheries rich in data and capacity.”

EAFM is part of an even wider concept, Ecosystem-based management (EBM) which embraces the wider planning of human activities in marine ecosystems (Arkema et al. 2006, Jamieson et al. 2010). Current developments within EBM include the marine (spatial) planning and the evaluation of regional ecosystem status, often using an indicators approach. Both these topics are beyond the scope of the present review.

Whilst most people can probably agree with the broad aims, there has followed considerable debate about different interpretations of EBM and EAFM (Jamieson et al. 2010) and how to actually implement them (Latour et al. 2003, Browman and Stergiou 2004, Hall and Mainprize 2004a, b, Hilborn 2004, Pikitch et al. 2004, Walters and Martell 2004b, Francis et al. 2007, Moloney et al. 2013). Within EAFM, one particular strand of debate has been the idea that single-species stock assessment models have failed and need replacing with multi-species models. In Section 3.3.2 we have already seen some of the issues with multi-species models in terms of data needs although also showing some of the insights these models can provide. In the late 1990s, Beverton (1998) and Pope et al. (2006) looking back over four decades of fisheries management failures in the Atlantic suggested that catch quotas had clearly failed to control over-capitalization. They also suggested that mixed-species models were needed in some cases because of mixed-fisheries, for example in the North Sea. Cardinale and Svedäng (2008) made a slightly different point when they argued that single-species stock assessments for Atlantic gadoids had provided sufficient information to trigger action – the problem in their opinion was not the quality of the scientific advice per se but the political will to act upon the advice when faced with competing social and economic pressures to set quotas at higher levels. In contrast, Kelly and Codling (2006) argued that single-species assessment models largely failed as the input data became contaminated by issues of mis-reporting and data with-holding as catch-quotas were reduced (Beverton 1998). This is hardly a novel concept (Gulland 1984) and it should have been anticipated that this problem would arise for Atlantic gadoid stocks. The vicious cycle of decreasing quotas and increased mis-reporting resulted in an increasing lack of confidence by all parties in the stock assessment outputs and a break-down in relations between the industry and policy/science (Beverton 1998). In this situation Kelly and Codling (2006) proposed that directly measured “quick and dirty” indicators could help and that these could also be applied in “data-poor” situations. They were also concerned about the increasing costs of providing advice through
the application of data-demanding models such as VPA, a cost which they considered to be unsustainable. A final point is that if fishing mortality rates (F) are reduced, the relative importance of natural mortality (M) increases. In standard single-species models it tends to be assumed that M is fixed across years and when F is high this is generally a reasonable approximation. However, when F decreases, changes in M over time become much more influential on the model outputs. More attention will have to be paid to changes in natural mortality in systems like the North Sea and Baltic where F has been significantly reduced and advice will need to be provided within a multispecies framework (ICES 2013a).

The arguments over which models are needed for EAFM rather miss the point that if the input data are garbage, the results will also be garbage (GIGO – garbage in, garbage out), this applies as much to multi-species as to single-species models. In relation to this debate it is worth going back to some words in the original FAO (2003) guidelines (Section 1.2):

“EAF is neither inconsistent with, nor a replacement for, current fisheries management approaches (e.g. as described in the FM Guidelines). Rigorously applying target resource-orientated management (TROM) approaches (with appropriate emphasis on the precautionary approach and rights-based allocation) would begin to help solve some of the current fisheries problems. Such action in the past could have prevented a large number of present ecosystem problems. Thus, in practice, EAF in the foreseeable future is likely to be developed as an incremental extension of current fisheries management practices.”

The role of ecosystem models in providing fisheries advice was further addressed in FAO (2008). The introduction strongly suggests that ecosystem models which incorporate a wider range of variables and processes compared with single-species models are essential for EAFM. Specifically models are needed to address conflicting objectives and to provide advice on trade-offs. Hypothetical examples cited include needing to reduce incidental mortality on species of conservation concern such as turtles; needing to balance economic opportunities against effort reductions and maximising economic returns across a mixed-fishery. The report is therefore discussing not only multi-species models but extensions which incorporate economics and ecosystem-service valuations (Barbier et al. 2010). Technical coupling may also exist, for example between the herring and lobster fisheries in New England (Grabowski et al. 2010). In such extreme cases, where the majority of the pelagic fish landed are used as bait, changes in management of the shellfisheries may affect the sustainability of the pelagic stocks (Lehuta et al. 2013). Fisheries scientists who have to provide advice and support to managers and stakeholders therefore need to be aware of the full range of options for modelling living systems including multifisheries interactions and bioeconomic extensions (Walters and Martell 2004b). This can however involve considerable investment in training and development, building collaborations with resource economists and social scientists, as well as the time needed to collect data and to develop and test the models themselves. This inevitably puts pressure on an often already over-burdened science community struggling to cope with the annual cycle of stock assessment advice provision (Garcia et al. 2003, Kelly and Codling 2006, Jennings and Rice 2011).
Francis et al. (2007) drew up 10 commandments in an attempt to translate the available high-level guidance on EAFM to practical advice for fisheries practitioners (Table 16). Although most of the examples they cited were not for SPF fisheries, all of their recommendations would apply. For fisheries on particularly short-lived SPF only commandments 3 and 9 may be of less relevance but even commandment 3 may be relevant to some longer-lived SPF, such as sardines (Pikitch et al. 2012a).

Table 16: Ten commandments for EAFM (Francis et al. 2007).

<p>| | |</p>
<table>
<thead>
<tr>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>Keep a perspective that is holistic, risk-averse, and adaptive.</td>
</tr>
<tr>
<td>2</td>
<td>Question key assumptions, no matter how basic.</td>
</tr>
<tr>
<td>3</td>
<td>Maintain old-growth age structure in fish populations.</td>
</tr>
<tr>
<td>4</td>
<td>Characterize and maintain the natural spatial structure of fish stocks.</td>
</tr>
<tr>
<td>5</td>
<td>Characterize and maintain viable fish habitats.</td>
</tr>
<tr>
<td>6</td>
<td>Characterize and maintain ecosystem resilience.</td>
</tr>
<tr>
<td>7</td>
<td>Identify and maintain critical food web connections.</td>
</tr>
<tr>
<td>8</td>
<td>Account for ecosystem change through time.</td>
</tr>
<tr>
<td>9</td>
<td>Account for evolutionary change caused by fishing.</td>
</tr>
<tr>
<td>10</td>
<td>Implement an approach that is integrated, interdisciplinary, and inclusive.</td>
</tr>
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</table>

The complexity of modern fisheries advice is also confusing to non-specialists and even among experts leads to arguments about whether a stock is being over-fished or is depleted (Agnew et al. 2013, Froese and Proelss 2013). From an EAFM view this can be seen as excluding a significant section of stakeholders from taking part in the management process and thus being in contravention of Commandment 10 (Froese 2004). Following this line of reasoning some of the factors which need to be considered in relation to developing EAFM plans for SPF fisheries are shown in

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Table 17.
Table 17: Some examples illustrating the range of factors which need to be considered for applying EAFM to SPF fisheries

<table>
<thead>
<tr>
<th>Relevant commandments</th>
<th>Issue</th>
<th>Examples</th>
<th>References</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>1,2,3,4,8</td>
<td>Is there a likelihood of stock collapse due to over-fishing during low productivity periods?</td>
<td>Hokkaido herring (<em>Clupea pallasi</em>)</td>
<td>Cushing (1971), Nagasaki (1973) Cushing (1976), Nagasawa (2001)</td>
<td>In many cases collapses likely initiated by environmental changes but accelerated by over-exploitation. Booms in SPF often seem to be initiated by increased survival of the early life stages leading to strong year-classes but reasons for declines are much more poorly understood and a wide variety of mechanisms have been postulated including changes in predation pressure (Peruvian anchovy), reduced parental quality (Pacific sardine), grazing down zooplankton (Black Sea).</td>
</tr>
<tr>
<td>14</td>
<td></td>
<td>North Sea herring (<em>Clupea harengus</em>)</td>
<td>Cushing (1976), Simmonds (2007), Dickey-Collas et al. (2010)</td>
<td></td>
</tr>
<tr>
<td>14</td>
<td></td>
<td>California sardine (<em>Sardinops sagax</em>)</td>
<td>Cushing (1971), Klyashtorin (1998), Lindegren et al. [, 2013 #7768;</td>
<td></td>
</tr>
<tr>
<td>1,8,10</td>
<td>Is the management system able to constrain over-capacity during periods when the stock is productive and rapidly reduce capacity when productivity declines?</td>
<td>Peruvian anchovy (<em>Engraulis ringens</em>)</td>
<td>Boerema (1973), Laws (1997), Klyashtorin (1998), Fréon (2008), Aranda (2009)</td>
<td>There is a history of over-capacity build-ups in this fishery, failures of open-access systems have been recognised, recently individual vessel quotas have been introduced to try and address this.</td>
</tr>
<tr>
<td>14</td>
<td></td>
<td>European anchovy (<em>E. encrasicolus</em>)</td>
<td>Daskalov et al. (2007)</td>
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<table>
<thead>
<tr>
<th>Relevant commandments</th>
<th>Issue</th>
<th>Examples</th>
<th>References</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>1,2,8,10</td>
<td>Does the management plan acknowledge changes in productivity and have mechanisms to review stock reference points?</td>
<td>European anchovy (<em>Engraulis encrasicolus</em>) Northern Adriatic</td>
<td>FAO (2013)</td>
<td>FAO recommends that the biomass reference points for this stock are revised.</td>
</tr>
<tr>
<td>1,2,10</td>
<td>Have inter-fisheries technical interactions been identified and considered?</td>
<td>Atlantic herring (<em>Clupea harengus</em>), New England</td>
<td>Grabowski et al., (2010), Lehuta et al. (2013)</td>
<td>Most of the herring catch is used as bait in the lobster fisheries, changes in management of the shellfisheries can impact the pelagic stock sustainability.</td>
</tr>
<tr>
<td>1,6,7,8</td>
<td>Are there credible links between environmental drivers and stock success and could they be used to management?</td>
<td>Peruvian anchovy (<em>Engraulis ringens</em>)</td>
<td>Laws (1997), Klyashtorin (1998), Fréon et al. (2008), Aranda et al. (2009)</td>
<td>Forecasts of ocean conditions conditions are used to aid management to some extent.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>S. American pilchard (<em>S. sagax</em>)</td>
<td>Nagasaki (1973), Yatsu et al. (2005)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Pacific herring (<em>Clupea pallasii</em>)</td>
<td>Deriso (2008)</td>
<td>Multi-factorial analysis suggested that hatchery reared pink salmon compete with or predate on juvenile herring, the relative tradeoffs between salmon stocking and rebuilding the herring stock would need to be evaluated.</td>
</tr>
<tr>
<td>Relevant commandments</td>
<td>Issue</td>
<td>Examples</td>
<td>References</td>
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<tr>
<td>1,8,10</td>
<td>Is the spatial distribution of the stock likely to change and could this lead to disputes over exploitation?</td>
<td>Best current example is Atlantic mackerel (<em>Scomber scomber</em>) although this was not included as an SPF in this review</td>
<td>Astthorsson et al. (2012), Hannesson (2013a)</td>
<td>The EU, Norway, Iceland and Faroes are currently in a damaging dispute over how to apportion Atlantic mackerel quotas following a shift in the distribution of the fish. This resulted in MSC sustainability certification for the fishery being suspended (MSC 2012). The dispute is still not resolved.</td>
</tr>
<tr>
<td>2</td>
<td>Are the stock assessment models used appropriate and robust to uncertainty?</td>
<td>Peruvian anchovy (<em>Engraulis ringens</em>)</td>
<td>Boerema (1973), Laws (1997)</td>
<td>Use of equilibrium-based models is widely held to have contributed to over-exploitation of the stock in the 1970s</td>
</tr>
<tr>
<td>2</td>
<td>Are the harvest control rules robust to changes in stock productivity?</td>
<td>Pacific herring (<em>C. pallasi</em>)</td>
<td>Haltuch et al. (2009), Cleary et al. (2010)</td>
<td>The HCRs should be tested in simulation against differing productivity scenarios</td>
</tr>
<tr>
<td>2</td>
<td>Does the fishery have significant discarding problems?</td>
<td>Sardine (<em>S. pilchardus</em>), Herring (<em>C. harengus</em>)</td>
<td>Stratoudakis &amp; Marçalo (2002), Borges et al. (2008)</td>
<td>Not usually an major issue in pelagic fisheries but “slipping” can occur</td>
</tr>
<tr>
<td>2</td>
<td></td>
<td>Various species</td>
<td>Akyol (2003)</td>
<td>Discarding is an issue in some coastal fisheries where there is not a market for trash-fish</td>
</tr>
<tr>
<td>3</td>
<td>Could harvesting truncate the age structure of the stock?</td>
<td>Longer-lived SPF such as sardines</td>
<td>Murphy (1967)</td>
<td>Impacts of age truncation on egg quantity and quality have been studied in non-SPF species but Murphy cites age-truncation as a factor in collapse of the sardine stock due to a loss in buffering against a run of poor recruitments.</td>
</tr>
<tr>
<td>Relevant commandments</td>
<td>Issue</td>
<td>Examples</td>
<td>References</td>
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<tr>
<td>3</td>
<td>Could harvesting truncate the age structure of the stock? Con/td</td>
<td>Atlantic herring (C. harengus)</td>
<td>Hempel &amp; Blaxter (1967)</td>
<td>Egg weight varies considerably between different spawning stocks, in groups where most fish small, egg weight related to size of mother but in groups comprised of older fish such correlations vanished</td>
</tr>
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<td></td>
<td></td>
<td></td>
<td>Bang et al. (2006)</td>
<td>In controlled trials, parental effects were detected on herring larval length, yolk-sac volume and condition although they could not be clearly linked to parental age.</td>
</tr>
<tr>
<td>4</td>
<td>Could the fishery affect the spatial of the stock?</td>
<td>Herring (C. harengus)</td>
<td>Schmidt et al. (2009)</td>
<td>Loss and re-colonisation of spawning grounds in the North Sea</td>
</tr>
<tr>
<td>6,7</td>
<td>Are the bottom-up effects on other ecosystem components understood well enough to set ecologically safe harvest levels?</td>
<td>Peruvian anchovy (E. ringens)</td>
<td>Duffy (1983), Hays (1986), Weimerskirch et al. (2012)</td>
<td>Fisheries may exacerbate problems for predators during El Niño years</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Furness et al., (Furness and Tasker), Frederiksen et al. (2004), Poloczanska et al. (2004), Wanless et al. (2005), Frederiksen et al. (2006), Frederiksen et al. (2007), Daunt et al. (2008)</td>
<td>Introduction of spatial fisheries closures seems to have brought benefits although environmental changes also affect the sandeels</td>
</tr>
<tr>
<td>Relevant commandments</td>
<td>Issue</td>
<td>Examples</td>
<td>References</td>
<td>Comments</td>
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<tr>
<td>6,7</td>
<td>Are the bottom-up effects on other ecosystem components understood well enough to set ecologically safe harvest levels? Con/td</td>
<td>Small planktovorous fish</td>
<td>Daskalov et al. (2007)</td>
<td>Trophic cascade from over-exploitation of small planktovorous fish in the Black Sea</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Seabirds Gulf of Mexico</td>
<td>Velarde et al. (2013)</td>
<td>Changes in seabird diets may act as early warning for SPF stock productivity fluctuations</td>
</tr>
<tr>
<td></td>
<td>Will bottom-up effects of harvesting the SPF be in conflict with other stakeholders needs?</td>
<td>Role of menhaden (B. tyrannus, patronus) as forage fish</td>
<td>Franklin (2007)</td>
<td>Harvesting of menhaden has been a source of conflict with the recreational fisheries sector who feel the fishery is damaging sport-species.</td>
</tr>
<tr>
<td>6,7,8</td>
<td>Could the SPF stock itself be affected by other fisheries - top-down effects?</td>
<td>Baleen whales on krill</td>
<td>Laws (1977), Fraser et al. (1992), Croxall et al. (1992)</td>
<td>Possible predator release due to historical fishing leading to increases in SPF abundance and possibly increases in other Antarctic predators such as penguins.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Cod (G. morhua) on herring (C. harengus)</td>
<td>Fauchald (2010)</td>
<td>Over-fishing on cod may have allowed herring to increase in the North Sea</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Cod (G. morhua) on sprat (S. sprattus)</td>
<td>Casini et al. (2008)</td>
<td>…and sprat in the Baltic Sea</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Herring (C. harengus) on cod (G. mohua)</td>
<td>Cushing (1980)</td>
<td>Over-fishing of herring may have facilitated increases in gadoid stocks but see Daan et al. (1985).</td>
</tr>
<tr>
<td>Relevant commandments</td>
<td>Issue</td>
<td>Examples</td>
<td>References</td>
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</tr>
<tr>
<td>6,7,8</td>
<td>Could the SPF stock itself be affected by other fisheries - top-down effects? Con/td</td>
<td>Predatory fish on small planktivorous fish</td>
<td>Daskalov et al. (2007)</td>
<td>Decline in predatory fish led to increase in small planktivorous fish in the Black Sea</td>
</tr>
<tr>
<td>5</td>
<td>Could the fishery impact the SPF habitat?</td>
<td>Seabed damage from anchoring by boats harvesting small fish for use as tuna bait</td>
<td>Gillett (2011), IPNLF (2012)</td>
<td>Not generally a major issue with pelagic fisheries where the gear are deployed in the water column.</td>
</tr>
<tr>
<td></td>
<td>Could other habitat quality factors impact the SPF stock?</td>
<td>Menhaden (<em>B. tyrannus</em>)</td>
<td>Dykstra &amp; Kane (2000), Del Rio et al. [, 2010 #7635;</td>
<td>Decreasing inshore water quality associated with intensive agriculture may be causing fish health problems</td>
</tr>
<tr>
<td>6</td>
<td>Does the fishery have significant impacts on endangered, threatened or protected species?</td>
<td>Gannets (<em>Morus bassanus</em>) in mackerel (<em>S. scombrus</em>), herring (<em>C. harengus</em>) and argentine (<em>Argentina silus</em>) fisheries</td>
<td>Pierce et al. (2002)</td>
<td>In many cases technical measures or changes in fishing practice can reduce direct impacts - by-catch issues.</td>
</tr>
<tr>
<td></td>
<td>Small cetacean interactions with purse-seine fisheries</td>
<td>Wise et al. (2007), Hamer et al. (2008)</td>
<td></td>
<td>Small cetaceans are attracted to the fishing grounds and interactions with gear occur but these may be under-reported</td>
</tr>
<tr>
<td></td>
<td>Seabirds</td>
<td>Cury et al. (2011)</td>
<td></td>
<td>Meta-analysis which suggested that seabirds suffer reduced and more variable productivity if prey availability falls below one-third of maximum observed long-term prey biomass.</td>
</tr>
<tr>
<td>Relevant commandments</td>
<td>Issue</td>
<td>Examples</td>
<td>References</td>
<td>Comments</td>
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<tr>
<td>10</td>
<td>Are there political issues which could lead to poor management?</td>
<td>European anchovy (<em>Engraulis encrasicolus</em>)</td>
<td>Mulazzani et al. (2013)</td>
<td>Levels of co-operation between states managing a common SPF resource were highly variable comparing fisheries in the Bay of Biscay and the Adriatic.</td>
</tr>
<tr>
<td></td>
<td>Are there particular end-users whose interests need to be safe-guarded?</td>
<td>Peruvian SPF fisheries</td>
<td>Decreto Supremo N8 001-2002-PRODUCE cited in Tacon and Metian (2009b)</td>
<td>Species such as jack and chub mackerel are reserved for the human consumption market</td>
</tr>
<tr>
<td></td>
<td>Are the economic drivers on the fishery well-enough understood so that impacts of management options can be evaluated?</td>
<td>Peruvian SPF fisheries</td>
<td>Fréon et al. (2008)</td>
<td>Interactions between stock productivity, product pricing and fishing capacity need to be considered.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Various case studies</td>
<td>Pikitch et al. (2012a)</td>
<td>EWE models used to explore consequences of different harvest strategies. Some simple bioeconomic analysis is included.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>North Sea multispecies including herring, sprat and sandeels</td>
<td>Dickey-Collas et al. (2013)</td>
<td>Discuss results from the ICES SMS model which includes somebioeconomics. Impacts on economic yields and on SPF availability to other predators of different SPF harvesting strategies were explored.</td>
</tr>
</tbody>
</table>
Historically many SPF fisheries have declined severely under excess fishing pressure, often to the extent that they are used as examples of stock collapse (Beverton 1990). In many cases environmental changes have probably been a significant factor but failure to reduce exploitation rapidly enough accelerated the decline (Sharp and McLain 1993, Dickey-Collas et al. 2010). This creates a dilemma for fisheries management – if a stock is going to disappear anyway then what is the point in limiting fisheries extraction. A good example is the S. American pilchard/Pacific sardine – no-one knows whether it would have persisted off California if fisheries rates had been lower (see Section 3.5) but this species has undergone through similar changes in abundance throughout the Pacific suggesting wider environmental drivers (Kawasaki 1993). In the face of this problem the ecosystem-based approach recommends that managers should seek to maintain the stock for as long as possible in order to:-

- Maximise the probability of the stock re-building
- Minimise the collateral impacts on other ecosystem components such as seabirds, marine mammals etc.

During periods of reduced SPF productivity considerable stress will be placed on other predators, especially ones which have limited ability to switch to alternate prey (see Section 3.3). It is likely that fisheries will need to be rather rapidly restrained to minimise competition with other components of the food-web. This can be difficult if excess catching and processing capacity has built up (Laws 1997, Beverton 1998, Fréon et al. 2008) and probably impossible if suitable management bodies, with the authority and resources to control the fishery, are not in place (Simmonds 2007). During this review few examples of management plans which specifically acknowledge that the stocks can enter different production phases could be found. One exception is Pacific sardine on the American west coast where the management plan has included a temperature-based switch designed to reduce exploitation rates if the stock enters a low productivity phase. This switch is however currently removed due to uncertainty about the strength of the environment-recruitment relationship (Jacobson and McClatchie 2013).

5.3. Particular issues with regard to EAFM of SPF stocks

Add in new refs (Hara 2013)

The aim of fisheries management is generally to ensure that sufficient biomass remains after the fishing season to allow the stock to replenish itself while allowing the fishery to maximise its catch. Because fisheries and processors struggle to cope when catch quotas change radically from year to year, some management systems incorporate mechanisms for inter-annual stability in quota setting. Under EAFM it is also important to consider if sufficient fish biomass will remain so that predators are not adversely affected, although the relative importance of wildlife conservation versus human exploitation issues in fisheries is a societal, not a scientific, choice (Walters and Martell 2004b, Hannesson 2013b). Given an adequate assessment of the status of the SPF stock, advice can then be provided on the levels of catch
which should result in sufficient mature biomass remaining to avoid poor recruitment. The levels of allowable landings are often actually set by administration departments on the advice from scientists (Aranda 2009). Administrations are often subject to multiple pressures from the fishing industry, politicians, processors and other stakeholders with the result that the catch quotas set have often exceeded the scientific advice (Daw and Gray 2005). In this essentially command-and-control model, levels of trust between different stakeholders is often low resulting in the quality of the scientific advice being contested (Glenn et al. 2012) which can allow the administration further room for manoeuvre and for setting potentially excessive catch quotas. Whilst it is under-understandable that this can happen, it is a dangerous route to take. Although scientific projections of short and medium-term stock trajectories frequently have to be revised, and often are shown subsequently to have retrospective bias, following the advice overall results in fewer stocks becoming over-exploited than if advice is ignored (Rice and Cooper 2003). Similarly taking prompt action when stock productivity declines is more likely to result in stock re-building than where action is delayed (Murawski 2010).

Because of the dangers of administrations over-riding scientific advice, many stocks are now managed using plans which include harvest-control rules (HCR). The essential idea of HCRs is that they constrain the management options such that if the stock does X, then management must do Y (Caddy and Mahon 1998, Pikitch et al. 2012a). Rules can be relatively simple, as in the case of Pacific herring, or become rather complex, as in the case of many European fisheries (Froese et al. 2010). It is important that the performance of HCRs is tested in simulations before the stock gets into problems so that there is a good probability that the rule will work when the stock gets into problems. This is especially true for most SPF where productivity fluctuates strongly. For example, Cleary et al. (2010) examined the performance of Pacific herring HCRs and concluded that whilst they should perform well when the stocks are productive they perform poorly when stocks are in an unproductive mode. This is because the HCRs included a fixed limit referene point, set at $0.25* B_0$ (where $B_0$ is an estimate of the biomass in an unfished situation), if the stock falls below this point, the target harvest is zero i.e. the fishery is closed. This limit reference point was designed to allow a minimum escapement which would avoid recruitment over-fishing and allow a depleted stock to rebuild but was defined using observatons from when the stocks were in a productive mode. The conclusion was that HCRs set on the basis of average stock performance can be over-optimistic unless data are available covering the full range of stock productivity modes (Haltuch et al. 2009). For stocks thought to be affected by multi-decadal oscillations this implies that 40-50 years of observation data may be required. This is similar to the time-scale over which climate-change may have significant impacts adding a further complication. Pikitch et al. (2012a) modelled the performance of a variety of potential HCRs on SPF stocks. The best strategy was reported to be a hockey-stick rule where fishing is stopped if biomass falls below a critical level and is then increased gradually as biomass increases. The least sustainable strategies were constant F or constant yield rules. In relation to environmental effects on the stock and recruit dynamics of Pacific sardine ($S. sagax$) it has been suggested that $msy$-based management targets should all be reduced during unfavorable regimes. Unfortunately a new production regime can only be estimated some years after a
shift but many types of management targets might work well, as long as targets are reduced during periods of unfavorable environmental conditions (Yatsu et al. 2005). Ultimately the performance of management plans and HCRs can only be judged by observing a reduction in the proportion of stocks presently classified as depleted or over-exploited (Cadrin and Pastoors 2008).

Reference points and targets have now been developed for many of the larger SPF stocks against which the stock and exploitation status can be judged (Table 18). Despite this progress the status of many stocks remains uncertain (Cadrin and Pastoors 2008). This may apply particularly to short-lived species, including many SPF, where the stock biomass is strongly influenced by inter-annual fluctuations in recruitment and where the strength of the incoming year-class can be difficult to estimate with precision. Various forms of direct biomass estimation are normally applied to such stocks including total and daily egg production methods (Shelton et al. 1993, Lo et al. 2001), acoustics, trawl (Watanabe and Nishida 2002) and aerial surveys (Hill et al. 2012a). Problems typically arise when disparate trends are given by the different methods generating uncertainty in the assessment (PMC 2011).

According to Article 61 (3) of the 1982 United Nations Convention on the Law of the Sea (UNCLOS 1982), coastal State fisheries management measures must be designed to restore and maintain fish stock sizes that can produce maximum sustainable yields. This obligation has been given the deadline of 2015 by the World Summit on Sustainable Development in Johannesburg in 2002. Within Europe this target date appears impossible to hit (Froese and Proelß 2010) but this does not reduce the obligation to define \( msy \)-based targets for stocks. For stocks whose productivity fluctuates strongly over time, which includes many SPF, defining fixed \( msy \) biomass targets may however be impossible. In these cases \( F \) based targets may be more appropriate. However, using \( F_{msy} \) as a target has similar dangers to using \( B_{msy} \) as a target – any overshoot leads to excessive mortality which will push the stock towards an over-exploited state from which it may not return. It has therefore been proposed that \( F_{msy} \) should be used as an upper limit on fishing mortality rather than a target (Caddy and Mahon 1998). Within Europe, member states and the EU subscribed to the MSY objective almost thirty years ago in the 1982 UN Convention on the Law of the Seas. They then reiterated it in the 1995 UN Fish Stock Agreement, in 2002 in the Johannesburg Declaration and finally in 2010 in Nagoya. The adoption of MSY wording in international policy documents has unfortunately led to the widespread promotion of msy as a target, for example within MSC sustainability certification whereas an even more precautionary approach may be needed. For SPF stocks, Pikitch et al. (2012a) suggested that fishing at half \( F_{msy} \) would result in a low probability of stocks collapsing and would reduce the impacts of SPF exploitation on other dependent species such as seabirds.

For short-lived species such as sandeel, ICES currently interprets the \( msy \) concept as using \( B_{msy} \) estimates as the default value for MSY \( B_{escapement} \). This escape strategy should retain a stock that is sufficient for successful recruitment and which can also provide an adequate resource for predators (ICES, 2010). The justification for this argument is that because the fish are exploited over only a few year-classes, there will be little additional
surplus production generated by growth above what is immediately apparent; the priority is therefore to prevent recruitment overfishing. Norwegian capelin (M. villosus) is also managed using a B\text{escapement} strategy. For North Sea sprat (S. sprattus) some preliminary work towards the establishment of an MSY B\text{escapement} has been undertaken but the associated uncertainties have not been sufficiently examined to be allow advice to be provided according to an escapement strategy at this time. The value of MSY B\text{escapement} should also take into account the uncertainties in the final assessment year as well as in the estimates of incoming recruitment. To ensure precautionary exploitation ICES considers that advice for stocks such as North Sea sprat should be based on an F\text{msy} proxy. For short-lived species, natural mortality (M) is considered as a potential F\text{msy} proxy (ICES, 2013b). This largely accords with guidance from FAO that for SPF, fishing mortality should not exceed natural mortality. For new fisheries where there is a lack of time-series, approximate rules of thumb relating F\text{msy} to natural mortality (which can itself be estimated from life-history characteristics) may be the only approach available (Caddy and Mahon 1998).

For longer-lived SPF such as North Sea herring (C. harengus) B\text{msy} will be larger than the biomass level which avoids significant risk of recruitment over-fishing (B\text{pa}) so B\text{escapement} is inappropriate. Because the fish are longer lived, aged-based stock assessment methods can be used and the assessments are usually tuned using commercial and research trawl, acoustic surveys and larval-based estimation of SSB (ICES 2012b). The management plan for North Sea herring is based on precautionary biomass limits established in 1998 but which have been re-assessed since. A value for F\text{msy} has been agreed at 0.25 but it was noted that m\text{sy} reference points may also change over time and a higher level at 0.3 has also been suggested. The joint EU-Norway management plan aims to maintain SSB above 800 Kt (B\text{pa}) but with a stability constraint of 15% inter-annual TAC movement.

A further problem is that in mixed fisheries it has been shown that it is not possible to attain MSY for all the species at the same time (Mackinson et al. 2009b). There therefore needs to be societal choice regarding whether emphasis should be placed on demersal or pelagic yields. Other approaches favour estimating maximum sustainable economic yield (MSEY) which takes into account some of these considerations. With mixed fisheries MSEY, multi-species models, incorporating fisheries economics data, are clearly needed as tools on which to base advice.

5.4. What is the present status of SPF stocks?
In 1973, Suda presented an analysis of the potential for development of fisheries for unconventional species. It was suggested that an additional 21 to 30 Mt of pelagics, 15 to 19 Mt of demersals and 6 to 7 Mt of cephalopods might be available, a total of around 44 Mt bringing total global catches up to between 93 to 110 Mt (Suda 1973). Marine capture fisheries yields actually peaked close to this estimate (86.4 Mt in 1996) but have since been fluctuating around the 80 Mt level (FAO 2012). The World Summit on Sustainable Development produced the Johannesburg Plan which demands that all fish stocks be restored to the level that can produce maximum sustainable yields by 2015. Given global progress with re-building depleted stocks it is almost impossible that this can be achieved although some significant improvements in fisheries management have taken place (Froese and Proellß
Stocks assessed as being over-exploited need credible rebuilding strategies whilst stocks being fully exploited require careful management to maintain their productivity. Suda’s 1973 prognosis was a bit optimistic in retrospect since only 12.7% of global stocks are thought to be presently under-exploited (Suda 1973).

Regarding the main SPF stocks (FAO 2012), Peruvian anchoveta is assessed as being fully exploited. In the Atlantic, stocks of herring (C. harengus) are being fully exploited whilst sandeel (Ammodytidae) and capelin (M. villoosus) are being over-exploited. In the central Atlantic most SPF stocks are being fully exploited, apart from sardine (S. pilchardus) for which there may be some additional potential. In the Mediterranean, the main SPF stocks (S. pilchardus and E. encrasicolus) are all assessed as either fully exploited or overexploited. The situation in the Black Sea with regard to sprat (S. sprattus) and anchovy (E. encrasicolus) has recovered somewhat from the drastic 1990s decline but these stocks are still considered as being fully exploited or over-exploited. In the southwest Atlantic, Brazilian sardinella (S. brasiliensis) is thought to be being over-exploited although may be recovering whilst Argentine anchovy (Engraulis anchoita) may be under-exploited (Pastous Madureira et al. 2009). Off S. Africa, pilchard (S. sagax) was at high biomass in 2004 and was being fully exploited but it has declined substantially since and is currently being fully or over-exploited. In contrast the status of S. African anchovy (E. capensis) has improved and it is being fully exploited. Growth in catches in the eastern Indian Ocean has continued but worryingly is attributed largely to “unidentified marine fish”. It is likely that previously un-exploited species are now being targeted but with a lack of reliable data it is impossible to evaluate these trends. In the western Indian Ocean only 6% of species overall are thought to be non-fully exploited.

Many of the major SPF fisheries are now subject to sustainability audits and certification. In terms of global seafood one of the largest certification schemes is overseen by the Marine Stewardship Council. This scheme has been subject to significant criticism with regard to a lack of rigour in defining biomass targets for sustainable stocks and the costs of objecting to a certification (Jacquet et al. 2010, Christian et al. 2013). In relation to EAFM, other problems are that MSC certification does not currently look deeply into the social issues associated with a fishery, nor other operational criteria with environmental costs such as fuel efficiency. An additional criticism is that the costs of obtaining certification favour large over smaller operations and that the resulting spread of sustainability certified products skews the market away from lower-impact fisheries and those in developing countries (Jacquet and Pauly 2008). In relation to SPF there is some evidence for this e.g. the small-scale spring-spawning Blackwater herring (C. harengus) fishery in the North Sea was one of the early entrants to the scheme but later pulled out. Although MSC has trialled methods for use in small-scale and data-poor fisheries, few of these have completed certification to date (Jacquet et al. 2010). Only a single fishery is certified in the Indian Ocean (Maldives pole and line skipjack tuna) as opposed to 81 fisheries in the north-eastern Atlantic alone (http://www.msc.org/track-a-fishery/fisheries-in-the-program/certified/north-east-atlantic accessed on 27 September 2013). Another criticism is that a number of fisheries
have been certified as being sustainably managed when they can be technically classed as being over-exploited (Froese and Proelss 2012). This has led to arguments over how to define “over-fished” and “depleted” (Agnew et al. 2013, Froese and Proelss 2013). These apparent contradictions come partly from historical changes in targets over time, for example until fairly recently ICES did not routinely report msy-based targets for stocks only precautionary based limits such as SSBpa which is designed to avoid recruitment over-fishing, this created problems for assessors who had to interpret the stock status in relation to the MSC guidance that the stock should be maintained “at a level consistent with Bmsy” (MSC 2008). In addition MSC accepts that stocks will fall below msy biomass targets at times – “there shall be evidence that the stock is at the target reference point now or has fluctuated around the target reference point for the past few years”. Stocks above SSBpa but below SSBmsy can therefore still achieve certification if there is a re-building program in place (Gutiérrez et al. 2012). The timeframe allowed for re-building to Bmsy is given as “the shorter of 20 years or 2 times its (the species) generation time. For cases where 2 generations is less than 5 years, the rebuilding timeframe is up to 5 years” (Marine Stewardship Council 2013). So for short-lived SPF, re-building plans should show results within a few years. For many stocks further problems stem from difficulties in defining biomass msy targets. Data presented in Froese and Proelß (2010) clearly show the wide range of SSBmsy estimates for various stocks in European waters depending on the method used to estimate the target. In these cases it may be preferable to define a fishing based target (Fmsy) as has been done within ICES for many stocks. In response to Froese and Proelss’s (2012) criticisms it is probably true that certification schemes need to tighten up their criteria with regard to F-based targets and evaluating the effectiveness of rebuilding plans, but we may also have to accept that rigid biomass targets may not always be practical, particularly for many SPF stocks where stock productivity fluctuates strongly over time (see section 3.5). Despite these legitimate concerns, the process of going through certification does encourage more openness and debate, particularly if all reports are made publically available. The process also exposes the fishing industry to new ways of thinking about its impacts, requires the fisheries to collect and analyse new data on their activities, and may help encourage moves towards less damaging practices (Tlusty 2012). The need for certifiers to see evidence also causes fishers’ organisations to put pressure on their governmental institutions to provide better support for data collection and analysis. A recent example is MSC certification for Gulf of Mexico sardine where a condition of certification was open dissemination of the fisheries information. There appear to be problems with this which could result in suspension of the certificate (Morgan and Flores 2013). All of these factors contribute to EAFM, particularly in regard to Francis et al.’s (2007) commandment number ten – “Implement an approach that is integrated, interdisciplinary, and inclusive” to which we should add the word “open” (Hinz et al. 2013). Perhaps the biggest concern with regard to current trends in certification is the dominance of large fisheries and the relatively small contribution of certification to improving fisheries management in developing countries (Jacquet et al. 2010, Bush et al. 2013).

Organisations such as MSC and Friends of the Sea (FOS) tend to focus on fisheries where at least part of the catch is used for human consumption whereas more industrial
fisheries can apply for certification to the IFFO. The level of detail examined differs between certification schemes but will generally cover most of the issues set out in Table 17. MSC audits focus around 3 principles (P1 Stock status; P2 Ecosystem issues; P3 Legal framework and compliance) where as the IFFO RS scheme focuses more on compliance and less on stock status (although this is noted in most of the reports). MSC has an appeals procedure although this has been criticized on grounds of the cost and the fact that appeals tend to focus on whether due process was followed rather than whether auditors have scored the fishery correctly (Jacquet et al. 2010, Christian et al. 2013).

A summary of the current status of some of the main SPF stocks is set out in Table 18 along with notes on whether they have been certified by MSC, IFFO or FOS. The ease of accessing stock assessment reports, management advice and certification audit reports varies considerably between stocks and schemes. In Europe, ICES has a policy of publishing the full stock assessment reports openly on the internet in addition to shortened summaries (although occasionally reports are delayed and a good knowledge of which expert group is responsible for compiling each report is needed to find material within the ICES website). In North America, Fisheries and Oceans Canada and National Marine Fisheries Service publish most of their assessments although they can sometimes be difficult to locate. In the USA many stock assessments are conducted at state level and accessing these reports can be difficult. In the Pacific, PICES (North Pacific Marine Science Organization, www.pices.int) runs a large number of special topic working groups but they do not deal routinely with fisheries stock assessment. Stock and fisheries information for S. American countries is less readily accessed and Asian (Japanese, Chinese, Indian) stock assessments are not easy to obtain (Ricard et al. 2012). For Antarctica a lot of information is available on the CCAMLR website although some reports have restricted access. More open systems would probably facilitate better management by allowing a wider range of stakeholders, including non-governmental organisations, to examine the information and more easily challenge the management system to justify its decisions. The data available (Table 18) suggest that whilst the major SPF fisheries (Peruvian anchoveta and Atlantic herring) are being relatively well managed improvements are still required in transparency and management plans. The status of smaller SPF stocks is generally poorer, for example in the Mediterranean where there are many examples of over-exploitation or a lack of formal assessments. The generally poor status of SPF in the Mediterranean has also been commented on in other studies e.g. Shannon et al. (2010). Globally some SPF stocks, including several certified as being sustainably managed, require urgent re-building although there is often uncertainty regarding the reasons for the low stock status – in these cases curtailing fishing effort is likely the only available management response. An indication of where management has failed is those stocks which are both “depleted” and being “over-exploited”. For several European SPF stocks there is a lack of data which prevents anything other than precautionary advice being issued. For most tropical SPF stocks, little or no publicly available information could be found and the associated fisheries are unlikely to be being managed in a pro-active manner (Purwanto 2003).
Globally there are not thought to be many SPF stocks which are currently “under-utilised” but one example often cited is Antarctic krill (*Euphausia superba*). Fisheries for Antarctic krill are managed through CCAMLR which is in the process of designing a new management system to better control the spatial distribution of fishing effort. This is likely to be a long-term project and in the mean-time the interim catch limit of 620 Kt will remain in place. Climate change is also likely to impact Antarctic ecosystems particularly strongly and this will have to be taken into account in developing fisheries management plans.
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<th>Species</th>
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<tr>
<td><em>Brevoortia patronus</em></td>
<td>Gulf of Mexico</td>
<td>Not over-exploited</td>
<td>IFFO</td>
<td>Management unit is entire Gulf of Mexico, fish form a single population (genetic data). Fishery has been managed under a regional FMP since 1978 but more than 90% of commercial harvest occurs in Louisiana waters. Harvest is controlled by temporal restrictions and technical measures set by the five state marine management bodies whilst inter-state coordination is through the Gulf States Marine Fisheries Commission (GSMFC). A range of fisheries dependent and fisheries independent data are collected, along with estimates of baitfish and recreational catches, and used in the stock assessments. Certification audit rated most criteria as high compliance but moderate for management plans, recommended that a better understanding of role of menhaden in the ecosystem is required.</td>
<td>Vaughan (2011), Platt (2010c), Peacock (2011e), (2012g), (Platt 2010c, Vaughan et al. 2011, Peacock 2013g)</td>
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\(^{15}\) Qualitative indicator of current stock status based on publicly available information: Green – Stock in good condition, fishery generally well managed; Yellow – Some issues, uncertainties or problems with the stock status or management; Red – Stock requires re-building or other serious problems; Blue – Inadequate data or no stock advice available, difficult or impossible to assess present stock status. Please note the colour shown should not be compared with the conclusions reached by independent certification schemes such as the IFFO and MSC for which the cited reports should be consulted.

\(^{16}\) IFFO – Internation Fishmeal and Fishoil Association RS - Responsible supply certification. IFFO RS also lists a wide range of fish species approved as by-product sources for processing – these have not been considered in the present report; MCS - Marine Stewardship Council, only fisheries certified in 2013 are included, several other SPF fisheries such as western Baltic herring are currently going through the assessment process; FOS – Friends of the Sea; SSASI – South African Sustainable Seafood Initiative

\(^{17}\) See the ICES and FAO websites for explanations of the fishing area codes. SSB - spawning stock biomass; F - fishing mortality per year; M – natural mortality per year; msy - maximum sustainable yield, pa – precautionary, lim – limiting reference points. Standard fisheries textbooks should be consulted for further explanation of terms such as $F_{0.1}$.
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| *Brevoortia tyrannus*  
Atlantic menhaden | East coast of US | Over-fishing but not over-fished | FOS (Chesapeake Bay) | Atlantic menhaden are caught for reduction and for bait. In recent years bait landings have been increasing and reduction landings decreasing. Total bait landings in 2011 were around one-third of reduction landings. The Atlantic menhaden fisheries are managed under a regional FMP since 1981. Since 2006 an overall harvest quota is in place which is regularly revised based on stock assessment. This quota is shared between states based on their landings history. Some transfer of quota between states is allowed. The threshold and target levels were revised in 2009 to be in line with maximum spawning potential. There was a technical mismatch between the overfishing (F) and overfished (SSB) reference points but this has been revised in 2012/2013. Multi-species modelling is on-going with the aim of developing ecosystem-based reference points. States are responsible for collecting data from the reduction and bait-fisheries which are used in the overall stock assessments. A variety of technical measures which vary with state, commercial purse-seines are prohibited in many states e.g. Rhode Island, South Carolina, Georgia and Florida. Other states have temporal and technical controls in place. For FOS certification no update audit reports seem to be available on the FOS website since initial certification in 2009 (accessed 1 October 2013). | FOS (2009c), (FOS 2009c, ASMFC 2012), Cosby et al. (2013) |
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<td><em>Clupea harengus</em></td>
<td>Atlantic herring</td>
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<td>Since 2003 Scotia/Fundy herring has been subject to an integrated fisheries management plan (IFMP) drawn up by the federal administration Department of Fisheries and Oceans (DFO) Canada. There are multiple spawning components in the 4VWX area and for management purposes the stocks are divided into four components: SW Nova Scotia/Bay of Fundy; offshore Scotia shelf; coastal Nova Scotia and Southwest New Brunswick migrant juveniles. Only the last fishery component lacks associated spawning areas. Nearly all the catch currently comes from the SW Nova Scotia component. The rating shown thus relates to the SW Nova Scotia component alone. Fisheries are mainly (84-90%) purse seine. The main management measure is annual catch quota with additional industry measures to try and avoid small fish. Limit biomass reference point defined, target for $F &lt; F_{0.1}$ but it has not been possible to determine $F$ in recent years. $msy$ targets not defined. SSB index from acoustic surveys is currently above average except for German Bank area. Data are not combined in a formal stock assessment model but fisheries independent assessments by acoustics and industry observations are used in the assessments.</td>
<td>Fisheries and Oceans Canada (2013a)</td>
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<tr>
<td><em>Clupea harengus</em> con/td</td>
<td>Atlanto-Scandian herring (Norwegian spring spawning herring)</td>
<td>SSB above MSY(<em>{\text{trigger}}) and with F&lt;(F</em>{\text{msy}}). Recruitment is thought to be affected by climate and stock may be entering a less productive phase as year-class strength since 2004 has been weak.</td>
<td>MSC(^{18})</td>
<td>A long-term management plan in place through North East Atlantic Fisheries Commission (NEAFC). The stock is jointly managed by the EU, Faroes, Iceland, Norway and Russia. The aims of the plan are to maintain SSB above (B_{\text{lim}}) and to keep F below 0.125. If SSB falls below (B_{\text{lim}}), fishing reduction rules are specified. The main management measure is by catch quota. The TAC is set at the stock level using assessments conducted through ICES. Although the overall TAC has been agreed there have historically been disputes about how the TAC should be shared out. Because of recent reduced recruitment biomass may fall below SSB(_{\text{trigger}}) and NEAFC asked ICES in 2013 to provide advice on adjusting the reference points. ICES noted positive retrospective bias in historical stock assessments for this stock but did not recommend changing the reference points at this time.</td>
<td>DNV (2009), (2010), (DNV 2011), (ICES 2013b)</td>
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<td>Atlanto-Scandian herring (Iceland including ICES Division IVva)</td>
<td>As above</td>
<td>IFFO</td>
<td>Iceland is part of the Atlanto-Scandian management system described above. The IFFO audit raised some concerns around failure to internationally agree a herring TAC for 2013 (this was of concern particularly in relation to recent poor recruitment levels for this stock).</td>
<td>Platt (2010a), Peacock (2011b), Peacock (2012b), Peacock (2013b), (DNV 2011)</td>
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\(^{18}\) There are numerous fisheries certified for herring within the same stock – MSC aims to gradually harmonise these over time. Where possible the most recent, harmonised public certification reference has been cited.
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<tr>
<td>Clupea harengus con/td</td>
<td>Iceland summer-spawning</td>
<td>SSB rebuilding since 2011 but $F$ is increasing to just above $F_{m_{sy}}$</td>
<td>IFFO</td>
<td>The stock consists of coastal herring which do not leave Icelandic waters. The fishery is managed nationally by Iceland but based on stock assessment advice from ICES and the Marine Research Institute. The main management tool is annual catch quotas and an Individual Tradeable Quota (ITQ) system is in place. There is no explicit capacity management although the ITQ system encourages indirect decommissioning and fleet consolidation. In 2012 ICES defined $m_{sy}$ based reference points for this stock as $F_{m_{sy}} = F_{pa} = F_{0.1} = 0.22$. The initial IFFO audit noted that TACs had been set in excess of science advice in some years and that this has re-occurred. Landings have also exceeded the TAC in recent years although this does not seem to have depleted the stock. The most recent IFFO audit also noted that the management objective of $F_{0.1} = 0.22$, which is in line with ICES suggested $F_{m_{sy}}$, is a precautionary approach but that this does not constitute an explicit long-term management objective. Recently <em>Ichthyophonus</em> infection in the stock has been a problem although this does not seem to have impacted increases in the mature stock size significantly.</td>
<td>Platt (2010e), (2012i), (2012j), ICES (2013e)</td>
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<tr>
<td><em>Clupea harengus</em> con/td</td>
<td>North Sea Subarea IV, Divisions IIIa, VIIId</td>
<td>SSB well above Bmsy, F below Fmsy. There are some indications that the stock-recruit relationship may have changed since 2001 to show more over-compensation</td>
<td>MSC</td>
<td>The North Sea herring consists of several autumn spawning components with use of different spawning grounds fluctuating over time. Sub-stock components are considered in the advice and a separate Downs TAC is maintained on an area (IVc-VIIId) basis. ICES (2013d) consider this to be an interim measure and recommend further research into management which would better protect the different sub-stock components. Since 1997 the stock has been managed under a joint EU/Norwegian management plan. The plan was updated in 2008 in light of reduced levels of recruitment. The revised rule specifies limit F for juveniles and adults at 0.05 and 0.25 respectively, when the SSB is above 1.5 million tonnes. There is a constraint on year-to-year change of 15% in TAC, when the SSB is above 800 Kt. The main management tool is annual catch quota. A new FMP is in negotiation. Vessel licencing varies with country e.g. Denmark introduced an ITQ system in 2007 which resulted in restructuring of the fleet. Stock assessment advice is provided by ICES and pa limits and msy targets have been defined. ICES plans to move to providing multispecies advice for North Sea herring in the near future. Advice is based on catch sampling, commercial records and fisheries independent surveys (acoustic, trawl and larval).</td>
<td>Schmidt et al. (2009), Payne et al. (2009), Andrews et al. (2012), Andrews &amp; Nichols (2012), (2013), ICES (2013d)</td>
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<td><em>Clupea harengus</em></td>
<td>W. Scotland Division Vla (N)</td>
<td>F below <em>msy</em> target but SSB fluctuating at around twice <em>B\text{lim}</em>(50 Kt). Historically SSB was much higher (400 Kt) but it is unclear if the stock can rebuild to this level as the stock-recruit relationship may have changed.</td>
<td>MSC (the certified fishery covers Vla (N) plus Vlb and Vb although most of the certified catches seem to be from Vla (N))</td>
<td>The fishery is managed under the EU CFP based on advice from ICES. The present management plan links SSB to F but with constraint on the maximum annual TAC variation. Trawl and purse seine boats from Scotland and N. Ireland and international freezer-trawlers have historically fished on the stock. There has been mis-reporting of catches between VlaN and IVa in the past but in recent years this is thought to be minimal. Assessments are based on commercial catch data and fishery independent acoustic survey. The stock probably consists of components from surrounding areas and ICES recommends that an integrated management strategy for these linked stocks may be required. Because of the unstable dynamics, <em>F</em>\text{pa}, <em>B</em>\text{pa} and <em>B</em>\text{msy} remain undefined but <em>F</em>\text{msy} has been estimated at 0.25. SSB is currently low compared with historical situation (pre-1977) although F is not excessive. Recent recruitment appears to be weak compared with the period 1957-1954. The WG noted that sea temperatures have also been increasing and that this might have impacts on the herring and that food-web interactions with seals may need to be taken into account.</td>
<td>Simmonds &amp; Keltz (2007), FCI (2012b), (2013), ICES (2013d)</td>
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In 2011 the European Commission delegated responsibility for setting quotas for certain stocks to member states where they are only fished by that state. This provision is applied to Clyde herring. Since 1998 the TAC has never been taken and landings continue at a low level. Data limited stock. | ICES (2013d) |
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<td><em>Clupea harengus</em> con/td</td>
<td>W. Ireland Divisions VIa(S) &amp; VIIb,c</td>
<td>Depleted – requires re-building, SSB is below B(<em>{\text{lim}}) and recruitment remains low. Despite steady catch reductions, F has probably remained above F(</em>{\text{may}}) (0.25) but may have fallen since 2010 although this interpretation is heavily dependent upon the stock assessment model used.</td>
<td></td>
<td>The fishery is managed under the EU CFP based on advice from ICES. The management unit was created in 1992 when it was separated from VIa (N). The bulk of the catches are taken by Irish and Netherland vessels. The stock assessments are based on commercial data and and acoustic surveys. There are however problems with the acoustic survey in separating VIa (N) and VIa (S) herring components. There is uncertainty in the appropriate values of terminal F to apply in the VPA analysis. Use of the acoustic data in 2012 as a tuning index appeared encouraging and suggested that recent F has declined to a greater extent than previously thought. The assessments suggest that SSB built up from 1957 to 1988 as a result of several particularly strong year-classes. Landings also increased until 1989 when they began to decline. Post-1988 recruitment appeared to drop dramatically resulting in a steady erosion of the SSB and increasing F. The stock has had three re-building plans, the most recent being developed in 2012. The new plan includes an HCR to reduce F if SSB&lt;B(<em>{\text{pa}}) but the suitable value for B(</em>{\text{trigger}}) requires evaluation. One interpretation of the historic patterns is that the stock is stuck in a low productivity mode related to some environmental or ecological change. Predation by grey seals may be a factor but consumption rates by seals are uncertain. The WG also noted that increased sea temperatures (related to the Atlantic Multidecadal Oscillation, AMO) might be suppressing recruitment but that cooling may occur over the coming few years as the AMO may be entering another negative phase.</td>
<td>ICES (2013d)</td>
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<td>Species</td>
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<tr>
<td><em>Clupea harengus</em></td>
<td>Irish Sea Divisions VIIa(N)</td>
<td>SSB above <em>msy</em> target, <em>F</em> just below <em>msy</em> target</td>
<td></td>
<td>The stock is managed under the EU CFP based on advice provided by ICES. However a long-term management plan remains to be developed and evaluated. Herring in the Irish Sea consist of two main components, Manx and Mourne. The main management measure is annual catch quotas which are split between Irish and UK vessels. The current fishery is only pursued by a limited number of vessels and landings remain low compared with the historical position. Stock assessments are based on catch data plus fishery independent research trawl, acoustics and larval surveys. There is however inter-mixing with Celtic Sea herring and Irish Sea stock components which complicates the stock assessments. Precautionary <em>F</em> reference points have also not been agreed but <em>F</em>(_{msy}) has been estimated at 0.26. The WG note in their general advice that spawning areas should be protected from activities such as gravel extraction and dredging. Within the UK this would normally be included as a consideration in Environmental Risk Assessments which must be produced for development projects such as offshore renewables, aggregates and oil and gas.</td>
<td>ICES (2013d)</td>
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<td>Species</td>
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<tr>
<td><em>Clupea harengus</em></td>
<td>Celtic Sea Divisions VIIa(S), VIIg,h,j (k).</td>
<td>SSB well above $B_{pa}$, $F$ below $F_{msy}$ and $F_{0.1}$</td>
<td>MSC</td>
<td>The stock is managed under the EU CFP based on advice provided by ICES. A long-term management plan has been proposed by the Pelagic Regional Advisory Council (RAC), evaluated as precautionary by ICES and adopted in 2013 as the basis for the advice. Spatial closures are used to protect spawning in sub-division VIIaS if SSB falls below 41 Kt, the size of vessels fishing in this area is also limited at all times. Catches are mainly by Irish vessels with some by French, German, Netherlands and U.K. Historically the stock had declined to a low in 2004 and was subject to a re-building plan which appears to have worked. Assessment data available include commercial landings and acoustic survey. Target $F$ is set at 0.23 below $F_{msy}$ which is estimated at 0.25, $B_{trigger} = 61$ Kt and $B_{pa} = 44$ Kt.</td>
<td>FCI (2012a), ICES (2013d)</td>
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<td>Species</td>
<td>Area</td>
<td>Status(^{15})</td>
<td>Certification(^{16})</td>
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<tr>
<td><em>Clupea harengus</em> con/td</td>
<td>Western Baltic Division IIIa, Sub-divisions 22-24</td>
<td>SSB below <em>msy</em>, F above <em>Fmsy</em></td>
<td></td>
<td>The fishery is managed under the EU CFP using scientific advice provided by ICES. There is no explicit management plan for this fishery which takes a mixture of North Sea autumn and Western Baltic spring spawners. Although both components are landed, the stock assessment is for the spring spawning component. There has been historical mis-reporting of catch areas but this has improved since 2009 as a result of quota transfers. Although reducing mis-reporting, this has led to more uncertainty in stock projections. Data are available on commercial catches but also fisheries independent data from acoustic, research trawl and larval surveys. The most recent assessment of the spring component suggests recruitment has been low since the late 1990s although the cause is unknown. Along with fishing this has led to SSB falling to a historic low in 2012. F(<em>{pa}), F(</em>{lim}) remain undefined for this stock although the working group have been exploring stochastic estimation approaches. This suggested a value for F(_{msy}) of 0.28 using a Beverton-Holt S-R relationship. This value is close to recent suggested values of 0.25 although the result is rather sensitive to the assumed form of the stock-recruit relationship. Along with North Sea herring, reduced recruits per spawner suggest that the stock may be in a low production period. Because the fleets also take autumn spawned North Sea herring the overall TACs for this area exceed the recommended TAC for the spring-spawning component. ICES recommend that a full evaluation of possible management plans for the WBSS stock be undertaken.</td>
<td>ICES (2013d)</td>
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<tr>
<td><em>Clupea harengus</em> con/td</td>
<td>Baltic proper</td>
<td>See below for stock status by Sub-division</td>
<td></td>
<td>The fisheries in the Baltic are mainly managed under the EU CFP using scientific advice from ICES. The main pelagic fisheries are based on pelagic trawl although there are small fisheries for herring which use trap-nets/pound-nets and gill nets, predominantly in coastal areas. A small amount of the catch is also taken with bottom trawls. The main countries involved include Denmark, Estonia, Finland, Germany, Latvia, Lithuania, Poland and Sweden. The Russian fleet targeting mainly sprat also catches a percentage of herring as by-catch. Changes in fleet structure have occurred as a result of EU accession of former Soviet bloc countries and EU vessel scrappage schemes. National quota is allocated in various ways with some countries introducing ITQ systems. The main management measure is annual catch quota but seasonal gear restrictions are also in place in some areas. National agencies are responsible for collecting fisheries data which is used to produce the stock assessments. As well as commercial catch data, regular research trawl and acoustic surveys are conducted and data used in the assessment process. Analytical stock assessments are undertaken by Sub-division for herring (25-29 and 32), excluding Gulf of Riga, Gulf of Riga, Bothnian Sea (30), Bothnian Bay (31 Exploratory) and for sprat in Subdivisions 22-32. At present advice is provided on a single-stock basis but work is being undertaken to develop multi-species approaches and to better align collection of fleet catch and economic data.</td>
<td>ICES (2013c)</td>
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<tr>
<td>Clupea harengus con/td</td>
<td>Baltic Sub-divisions 25-29 &amp; 32</td>
<td>SSB just above MSY $B_{\text{trigger}}$, F below $F_{\text{msy}}$</td>
<td></td>
<td>SSB fell steadily from 1980s and 1990s and F increased up till 2000. The stock has shown some recovery since. $l_{\text{in}}$ and $p_{\text{a}}$ reference points have been defined. MSY $B_{\text{trigger}}$ is set equivalent to $B_{\text{pa}}$ and $F_{\text{msy}}$ estimated at ~0.3 on the basis of stochastic multispecies simulation. $F_{\text{msy( multispecies)}}$. The simulations show that $F_{\text{msy}}$ for herring is relatively insensitive the abundance of cod. Multispecies $F_{\text{msy}}$ recommendations have not yet been tested against harvest-control rules and so are not accepted as precautionary at this time. In contrast the Bmsy for herring declines from around 1.5 Mt when cod SSB is around 100 Kt to just under 1.2 Mt if cod SSB is 450 Kt. This is a good example of how multispecies interactions can affect estimates of MSY reference points. The WG thus note that estimates of MSY biomass reference points are particularly sensitive to model choice for this stock and depending which approach is taken (single-species or multi-species) can lead to a different interpretation of the stock status. There have also been significant decreases in weight at age in recent years which has been linked to decreasing availability of copepod prey. The WG recommended that multispecies interactions should be taken into account in providing advice in future.</td>
<td>ICES (2013c)</td>
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<tr>
<td><em>Clupea harengus</em> con/td</td>
<td>Gulf of Riga Sub-division 28.1</td>
<td>SSB above MSY $B_{\text{trigger}}$ but F above $F_{\text{msy}}$</td>
<td></td>
<td>Herring in the Gulf of Riga are considered to be a separate stock. The fishery is mainly prosecuted by Latvia and Estonia and is based on trawls and traps. There are no explicit management objectives for this stock. Historically this stock increased from the late 1980s and this may be associated with an environmental regime shift. Estimates of reference points are however based upon the whole time-series. Since 2004 the main management measure has been an annual TAC which is split between Latvia and Estonia. Assessments are based on commercial catch data and fishery independent acoustic survey. Some of the catches from sub-divisions 25-29 &amp; 32 is taken from the Gulf of Riga and estimates of the proportion are reallocated in the assessment. In some years it has been possible to use environmental data to predict incoming year-class strength but the reliability of these relationships has not been constant over time. $B_{\text{pa}}$ and $B_{\text{lim}}$ are undefined but $F_{\text{pa}}$ is estimated at 0.4. MSY $B_{\text{trigger}}$ has been estimated and $F_{\text{msy}} = 0.35$. Predation by cod (<em>G. morhua</em>) is currently low.</td>
<td>ICES (2013c)</td>
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<tr>
<td>Bothnian Sea</td>
<td>Sub-division 30</td>
<td>SSB well above</td>
<td>$F_{\text{msy}}$</td>
<td>The fishery comprises mainly pelagic and demersal trawl and a small amount of catch using gillnets. Herring caught in gillnets can be attacked by seals and this can lead to some discarding of damaged fish. The stock assessments are based on commercial catch data with fisheries independent acoustic survey and trapnet tuning. In 2012 there were problems with funding for the acoustic survey and the impact of this on the stock assessment was pointed out by the WG. B and F, $F_{\text{lim}}$ and $F_{\text{pa}}$ limits are presently undefined but it is considered that they are not needed at this time due to the good stock status. $F_{\text{msy}}$ has been estimated to be 0.14 but is somewhat sensitive to the stock-recruitment function used.</td>
<td>ICES (2013c)</td>
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<td>Species</td>
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<tr>
<td><em>Clupea harengus</em> con/td</td>
<td>Bothnian Bay Sub-division 31</td>
<td>SSB increasing but F is also increasing</td>
<td></td>
<td>Herring are harvested by pelagic and demersal trawl and gill-nets. The main fishing is by Finland and Sweden. The assessment is based on commercial catch data only and the stock is considered to be data limited. No reference points have been defined. CPUE in trawl fisheries is tracked and shown to be increasing which may encourage over-capacity to build again. However, compared to historical levels in the 1980s present fishery effort is low.</td>
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References: ICES (2013c)
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<th>Species</th>
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<th>References</th>
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<tr>
<td><em>Clupea pallasii</em></td>
<td>British Columbia</td>
<td>Fished areas showing increasing SSB since 2010.</td>
<td></td>
<td>Herring have long been harvested by First Nations for use as food. During the 1930s to late 1960s a commercial reduction fishery developed. By mid 1960s the age structure of the stocks had been severely reduced and along with a run of poor environmental years led to strong declines in SSB. The commercial fishery collapsed and was closed in 1967 to allow stock re-building. During the 1970s the herring roe fishery developed leading to introduction of a fixed harvest rate in 1983. A series of strong year-classes during the 1970s help the stocks rebuild. The present-day fishery comprises commercial food and baitfish, spawn-on-kelp and roe products, a food, social, and ceremonial fishery for First Nations and some recreational catches. Pacific herring fisheries are managed under an IFMP by the Canadian federal Department of Fisheries and Oceans. Developing an ecosystem-based approach for defining biological reference points for Pacific herring is described as a priority research area for DFO. This recognises the importance of Pacific herring in the food-web. However, at present advice is based on a single-species approach. Advice is provided on five stock components within the region. Fisheries currently only operate in Prince Rupert District and Strait of Georgia due to low biomass in other areas. Fisheries are managed using an SSB-based harvest control rule. However, the effectiveness of the HCR under low productivity conditions has been questioned. Causes of low productivity in the currently un-fished stocks are not well understood.</td>
<td>Schweigert et al. (2010), Cleary et al. (2010), Fisheries and Oceans Canada (2012) (2013d)</td>
</tr>
<tr>
<td><em>Sardinella aurita</em></td>
<td>Canary Current</td>
<td>No known stock assessment</td>
<td></td>
<td>There is no recorded management of the fishery.</td>
<td>Ricard et al. (2012)</td>
</tr>
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<td>Species</td>
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<tr>
<td><em>Sardinella</em> spp.</td>
<td>Java Sea</td>
<td>Standardized CPUE analysis</td>
<td></td>
<td>There are serious concerns about large increases in fishing effort and strong falls in standardized CPUE which indicate very significant stock declines since 1990s. The fisheries appear to be largely un-regulated.</td>
<td>Purwanto (2003), Cardinale (2009)</td>
</tr>
<tr>
<td><em>Sardinella longiceps</em></td>
<td>Arabian Sea</td>
<td>No known stock assessment</td>
<td></td>
<td></td>
<td>Ricard et al. (2012)</td>
</tr>
<tr>
<td><em>Sardina pilchardus</em></td>
<td>ICES Division VIIe, VIIf</td>
<td>No stock assessment, stock has historically fluctuated in response to climate</td>
<td>MSC</td>
<td>The sustainability of the fishery was assessed by MSC using their risk-based framework due to lack of formal stock assessment. The fishery was assessed as being sustainable on the basis that the fishing methods Population links with adjacent stocks off Portugal and Bay of Biscay are unclear.</td>
<td>Southward (2005), Coombs et al. (2010), MRAG Americas Inc. (2010), Gasgoine &amp; Tindall (2011)</td>
</tr>
<tr>
<td></td>
<td>Bay of Biscay, ICES Divisions VIIIa,b,d and Sub-area VII</td>
<td>SSB declining below long-term average, current F may be close to Fmsy</td>
<td>MSC</td>
<td>Advice given on precautionary basis. Acoustic and egg-based survey estimates are available.</td>
<td>Bureau Veritas (2010), (2011), (2012), (2013), ICES (2013)</td>
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<tr>
<td>Sardina pilchardus con/td</td>
<td>Portugal, ICES Areas VIIc, IXa</td>
<td>SSB is well below long-term average, F rose sharply from 2008 to 2012 but may now have fallen somewhat</td>
<td>MSC</td>
<td>The certification was suspended in 2012 following stock assessment which showed sharply falling SSB and rising F. Certification was restored in 2013 following introduction of an emergency Fisheries Management Plan. Revised SSB estimates also show stock is in slightly better health than previously thought. Acoustic and egg-based surveys are giving discrepant signals. Assessment model was also changed in 2012 which has caused further shifts in the perception of the stock health.</td>
<td>Hough et al. (2009), Nichols et al. (2011, 2012), Nichols &amp; Scott (2013), ICES (2013)</td>
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<td></td>
<td>Mediterranean, Alboran Sea (GSA 01, 02, 03)</td>
<td>Stock being overfished, F&gt;M</td>
<td></td>
<td>Stock assessment is considered preliminary</td>
<td>FAO (2013)</td>
</tr>
<tr>
<td></td>
<td>Mediterranean, Alboran Sea (GSA 04)</td>
<td>Stock is fully exploited</td>
<td></td>
<td>Stock assessment is considered preliminary</td>
<td>FAO (2013)</td>
</tr>
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<td></td>
<td>Mediterranean, Gulf of Lion (GSA 07)</td>
<td>Fully exploited although F is currently low. Biomass requires rebuilding.</td>
<td></td>
<td>Biomass may be low due to reasons other than fishing pressure, FAO assess the stock as “collapsed”</td>
<td>FAO (2013)</td>
</tr>
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<td></td>
<td>Mediterranean, Southern Sicily (GSA 16)</td>
<td>Low to moderate exploitation rate but biomass remains low</td>
<td>msy reference points require exploration and definition</td>
<td></td>
<td>FAO (2013)</td>
</tr>
<tr>
<td></td>
<td>Mediterranean, Northern Adriatic (GSA 17)</td>
<td>Fully exploited, F increasing recently</td>
<td></td>
<td>Multispecies fishery with anchovy</td>
<td>FAO (2013)</td>
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<tr>
<td><em>Sardinae sagax</em> S. American pilchard (Pacific sardine/</td>
<td>Morocco (FAO 34)</td>
<td>No assessment accessible</td>
<td>FOS</td>
<td>No update audit reports available on FOS website since certification in 2009</td>
<td>FOS (2009b)</td>
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<tr>
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<td>Canada to N. Mexico</td>
<td>Stock biomass continues to decline since high in 2006/07, recruitment presently low compared with historical levels. Stock may be entering lower productivity phase.</td>
<td></td>
<td>Since 2001 a limited purse seine fishery has been developing in Canadian waters in addition to permitted First Nation and recreational catching – the sardine fishery is managed via an IFMP. The main control is via limited entry and annual catch quota which is shared between licence holders. Time and area closures also occur to protect salmon from excessive by-catch. The U.S. stock assessment is considered uncertain but provides the best available information, survey methods (total egg production, daily egg production, trawl-acoustic and aerial) are currently producing divergent trends. Stock distribution also highly spatially variable. The stock is listed in RAM.</td>
<td>Pacific Management Council (2011), Ricard (2012), Hill et al. (2012a), Cal. Dep. Fish and Wild. (2013), Fisheries and Oceans Canada (2013e)</td>
</tr>
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<td>Sardine/ Spanish sardine)</td>
<td>Regions XV-IV (Chile)</td>
<td>Since 2001 stocks of <em>S. sagax</em> have been at very low levels – probably due to environmental conditions</td>
<td>IFFO, SSASI</td>
<td>Lack of recording of by-catch although all is landed. Fisheries Development Institute methodology is not publically available so difficult to evaluate quality of the advice. Lack of transparency in quota setting process. More information on fisheries interactions with ETP species required. Sardine is primarily caught as by-catch in the anchovies fisheries.</td>
<td>Peacock (2011c), Peacock (2013e)</td>
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<td>Species</td>
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<td><em>Sardinops sagax</em> con/td</td>
<td>Gulf of California</td>
<td>There is some evidence that the stock productivity is declining once more although oceanographic conditions do not seem unfavourable. There are claims that declining stock status may be impacting other ecosystem components but other comments that seabird breeding has been good. There seems considerable uncertainty relating to whether ecosystem, stock productivity or fleet behaviour changes are occurring which require investigation.</td>
<td>MSC</td>
<td>Pacific sardine are taken in a multispecies purse-seine fishery in the central and southern Gulf. Species landed include Monterey sardine, thread herrings, mackerel, Japanese sardine, anchoveta and Bocona sardine (<em>Cetengraulis mysticetus</em>). Abundance and catches are highly variable in response to environmental conditions. In 2011/12, Pacific sardine represented around 19% of the total pelagic catch with the bulk being Bocona but in the past Pacific sardine have contributed up to 62%. Since 1993, the fishery has been managed by the federal government of Mexico. Minimum landing sizes and controls on gear and fleet capacity are in place. Closures are used to protect spawning areas. TACs are not used as a management tool. The fisheries management system does involve stakeholders. $F_{msy}$ has been estimated at 0.27 but use of this value in models led to oscillations. A value of 0.9MSY has been adopted as a target. A formal management plan was adopted in 2012 which incorporates a biologically acceptable catch (BAC) as $0.9F_{msy}$ which is regarded as equivalent to a Limit Reference Point (LRP). According to the plan the target reference point must be set lower than the BAC. Catches are monitored and hydroacoustic surveys conducted and the data used to produce virtual population analysis based stock assessments. The initial MSC audit raised a number of conditions relating to ecosystem impacts of the fishery, for example on thread herrings (<em>Opisthonema</em> spp.) and Pacific anchoveta (<em>Cetengraulis mysticetus</em>) which are also caught, and better monitoring of ETP interactions. Although progress was made on conditions, the 2nd annual audit found major non-conformance with dissemination of information from the fishery to all interested stakeholder.</td>
<td>Chaffee et al. (2011), Daume &amp; Sosa-Nishizaki (2012), Morgan &amp; Flores (2013), Velarde et al. (2013)</td>
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| Sprattus fuegensis  
Falkland sprat     | Baja (FAO 77)              | FOS                             |               | Fishery is shown as certified on FOS website but no audit reports are available (accessed 1 October 2013) |
| Sprattus sprattus  
European sprat     | Southeast Atlantic          | No known assessment or assessment not accessible |               | Not listed in RAM                                                                                     |
<p>|                  | Division IIIa (Skagerrak-Kattegat) | Index adjusted status quo catch recommended |               | Data limited stock. Fisheries in this area managed with joint agreements between the EU and Norway. The main control on the fishery is by annual catch quota set using advice from ICES. By-catch of herring in the sprat fisheries is an issue particularly in years of high sprat abundance or low herring recruitment. Countries such as Denmark and Norway have restrictions on the percentage of sprat catch which can consist of herring by-catch. Assessments are based on commercial catch data, fishery independent trawl surveys and acoustic survey targeting herring. Much of the sprat catch comes from coastal areas which are not well covered by these surveys and this causes problems for the assessments. The lack of consistency between surveys has resulted in excessively high uncertainty in stochastic multispecies model runs and analytical stock advice is not currently produced. No precautionary reference points have been defined for this stock. The fishery is generally limited by the herring by-catch restrictions and in recent years has not landed the allocated TAC. There is also major uncertainty as to the amount of migrations from the North Sea into IIIa. |</p>
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<tr>
<td>Sprattus sprattus con/td</td>
<td>Sub-area IV (North Sea)</td>
<td>SSB above Bpa, F below provisional Fmsy proxy</td>
<td></td>
<td>The fishery is managed under the EU CFP using scientific advice from ICES. There is no explicit management plan for the stock and the WG state that this needs to be developed and evaluated. North Sea sprats probably comprise a single population although there may be separate sub-populations in peripheral areas which could become locally depleted. Commercial catch data prior to 1996 are considered to be unreliable but data collection is improving. Herring are often taken as by-catch in the sprat fisheries and several countries (e.g. Norway and Denmark) limit the amount of by-catch as a percentage of sprat biomass. Assessments are based on commercial catch data with research trawl and acoustics surveys. Because sprats are short-lived it is necessary to provide in-year advice but this requires knowledge of the strength of the incoming year-class. To accommodate this the assessment cycle has been shifted to a July to June basis. The assessment was conducted using a stochastic multispecies model (SMS) which allows natural mortality to vary in relation to pressure from sprat predators. Because sprat are short-lived and sensitive to environmental and ecological conditions, Bmsy targets remain undefined and advice is based on pa reference points, i.e. the main aim of the management is to avoid recruitment over-fishing. Similarly Fmsy will vary over time so an escapement strategy is used. For 2014 an Fmsy-escapement of 2.5 was suggested as being appropriate. The main issues with managing the sprat fishery are similar to those on other short-lived pelagics such as anchovy.</td>
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<tr>
<td>Sprattus sprattus con/td</td>
<td>Sub-area VI, VII</td>
<td>Precautionary reduction in catches</td>
<td></td>
<td>The fishery is managed under the EU CFP using scientific advice from ICES. Data limited stock. The stock structure of sprat in the Celtic Seas is not clear and although the WG presents available data for both these divisions in one report section they recommend that further work is needed to define the appropriate management units. There are currently no management objectives and the fishery is not managed. A TAC is set for sprat in the English Channel (VIId,e) but this is the only place where this currently occurs. The fisheries for sprat operate sporadically and with variable timing with most catch being taken by smaller pelagic vessels that also target herring. There seems to be little information on levels of by-catch in these small-mesh fisheries. An acoustic survey conducted in the Irish-Celtic Sea can provide data on sprat but the survey timing was designed to coincide with the peak of herring abundance and shows highly variable results in terms of sprat biomass. A separate acoustic survey is conducted in the Irish Sea and has been used to produce an index of sprat abundance. Sprats are caught in the research trawl surveys but the gear is not optimised for catching pelagic species. For the English Channel, use of a Schaefer surplus-production model driven by length per unit effort data has been explored. This did produce an estimate of MSY. Current advice is based on lpue because the surplus production approach is exploratory.</td>
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<td>Species</td>
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<td>Certification(^{16})</td>
<td>Comments on management and certification</td>
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<tr>
<td>Sprattus sprattus</td>
<td>Subdivision 22-32 (Baltic Sea)</td>
<td>SSB above (msy) target, (F) just below (msy) target</td>
<td>(F_{msy}) target</td>
<td>Sprat fisheries in the Baltic are managed under EU and Russian catch quota systems. The pelagic fisheries in the Baltic proper tend to take herring and sprat simultaneously but relative quotas for different countries vary with region. There are a variety of national approaches to managing these mixed fisheries e.g. in Latvia the main target is sprat as they have little herring quota so the industry tries to minimise herring by-catch. The quality of the assessments can however be impacted by uncertainties in the catch composition data. Both (p_y) and (msy) reference points have been defined. Overall the stock appears healthy but is not currently subject to a management plan. In recent years the TAC has not been fully taken. The WG have been exploring the effects of taking into account multispecies interactions on the reference points. This shows that (F_{msy}) for sprat is rather sensitive to the abundance of cod and falls from around 0.6 to just under 0.2 over cod abundance range from 100 to 450 Kt. To date the modelling has considered weight yields and economics are not fully incorporated.</td>
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\(^{15}\) SSB: Spawning Stock biomass, \(msy\): Maximum sustainable yield, \(p_y\): Productivity

\(^{16}\) Certification refers to the management and certification status of the species.

\(^{17}\) ICES: International Council for the Exploration of the Sea
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<tr>
<td><em>Sprattus sprattus</em> con/td</td>
<td>Black Sea (GSA 29)</td>
<td>Moderate exploitation rates, ( F &lt; F_{\text{msy}} ) and reduced from 2010 and 2011. Currently the stock seem to be being sustainably exploited but it lacks an international management plan and the stock assessment has significant weaknesses.</td>
<td></td>
<td>Parts of the stock are managed by the EU for which precautionary annual quotas are set which are split between Bulgaria and Romania. There is no other relevant fishery management agreement among other Black Sea fishing countries. Turkey has enacted a number of regulations regarding season, spatial and depth aspects and minimum mesh sizes which are designed to protect the very young sprat. Ukraine set an independent TAC in 2012 and no information is available on management in Russian or Georgian waters. The main fishing is seasonal (Apr.-Oct.) using mid-water otter trawl, pelagic pair trawl and pound nets. In the Western part of the Black Sea catches declined after the late 1980s but has since rebuilt. Catch data have been supplied by Bulgaria, Romania, Ukraine, Turkey and Russia. Some fishery independent acoustic and trawl survey data are available but do not cover all waters. STEFC recommend that an international hydroacoustic survey covering all the relevant waters needs to be established to support stock assessments for this species. The stock assessment is conducted using integrated catch analysis (ICA). Catches are advised not to exceed 100 Kt. No ( F_{\text{msy}} ) reference points have been defined for this stock. ( F_{\text{msy}} ) is estimated as a proxy based on a limit reference exploitation rate. STEFC also expressed concern that the sprat fisheries may generate significant gadoid bycatch and discards for which there is currently virtually no information or monitoring.</td>
<td>FAO (2013), Tserkova (2013), STECF (2013)</td>
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19 The common name Black Sea sprat is also used for *Clupeonella cultiventris* which is found in freshwater, brackish and inshore marine waters. Because of its semi-anadramous nature this species was not included in the present review.
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<tr>
<td><em>Strangomera bentincki</em>&lt;br&gt;Araucanian herring (Chilean sardine)</td>
<td>Regions V-X (Chile)</td>
<td>Stock status appears healthy, some improvements in management process required</td>
<td>IFFO</td>
<td>Lack of recording of by-catch although all is landed. Fisheries Development Institute (IFOP) methodology is not publically available so difficult to evaluate quality of the stock advice. Lack of transparency in quota setting process. The species is also important for inshore artisanal fisheries.</td>
<td>Romito (2011a), Peacock (2013f)</td>
</tr>
<tr>
<td><em>Engraulis anchoita</em>&lt;br&gt;Argentine anchovy</td>
<td>Humboldt Current</td>
<td>No known assessment</td>
<td></td>
<td></td>
<td>Ricard (2012)</td>
</tr>
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<td></td>
<td>Argentina</td>
<td>Stock appears healthy, SSB assessed as being high compared with historical trends, recruitment average over recent years but some improvements in data collection required</td>
<td>MSC, FOS</td>
<td>Because of strong recruitment fluctuations assessment is mainly survey based. A biological reference limit has been set implicitly at 0.33*SSB&lt;sub&gt;max&lt;/sub&gt;. This BRL is designed to avoid recruitment over-fishing. &lt;em&gt;msy&lt;/em&gt; based reference points have not been defined. Additional information on by-catch of ETP species required.</td>
<td>Prenski et al. (2011)</td>
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| *Engraulis capensis* (encrasicolus)  
S. African anchovy            | South Africa                   | SSB and recruitments are currently low but have fluctuated in similar manner historically. Landings are below TAC and F is not considered to be excessive. | IFFO, SASSI   | Managed jointly with the sardine fishery. TACs are set on basis of avoiding recruitment over-fishing. Foodweb interactions are taken into account and spatial closures in place to protect predators such as penguins. A new Operational Management Procedure (OMP-13) is due to come into force which will require re-evaluation. | Peacock (2011a), (2013a)   |
| *Engraulis encrasicolus*  
European anchovy                | Division VIII (Bay of Biscay)   | SSB above $msy$  
$B_{escape}$, F below long-term average |               | ICES note a draft management plan was proposed in 2009.                                                                                                                                                                                                           | ICES (2013)                 |
|                                 | Division IXa (Portugal)         | No advice                                            |               | Lack of data on year-classes which form bulk of the fishery                                                                                                                                                                                                       | ICES (2013)                 |
|                                 | Mediterranean – Alboran Sea (GSA 01, 02, 03, partial 04) | No advice                                            |               | Stock not formally assessed                                                                                                                                                                                                                                     | FAO (2013)                  |
|                                 | Mediterranean, Gulf of Lion (GSA 07) | Biomass trends appear stable but fish weight is low, F is currently low but stock is considered fully exploited. |               | Stock problems may be related to non-fisheries ecosystem issues                                                                                                                                                                                                  | FAO (2013)                  |
| *Engraulis encrasicolus*  
con/td                         | Mediterranean, Southern Sicily (GSA 16) | Exploitation rate high – stock is over-exploited. | $msy$ reference points need to be explored and defined                                   |                                                                                                                                                    | FAO (2013)                  |
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<tr>
<td>Mediterranean, Northern Adriatic (GFCM GSA 17)</td>
<td>Sustainably exploited</td>
<td>FOS</td>
<td>This stock interacts with GSA 18 and with the sardine fishery. F has been increasing and FAO recommend that the biomass reference points be revised. FOS citations of stock status appear to be based on out-of-date reports although latest FAO report indicates this stock is being sustainably exploited.</td>
<td>FOS (2010), FAO (2010b), FAO (2013)</td>
<td></td>
</tr>
<tr>
<td>Mediterranean, Southern Adriatic (GSA 18)</td>
<td>No formal assessment</td>
<td></td>
<td>Acoustic survey and daily egg production method applied but better landings data required</td>
<td>FAO (2013)</td>
<td></td>
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<tr>
<td>Morocco (FAO 34)</td>
<td>No formal assessment</td>
<td>FOS</td>
<td>No update audit reports available on FOS website since certification in 2009</td>
<td>FOS (2009a)</td>
<td></td>
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<tr>
<td><em>Engraulis encrasicolus</em></td>
<td>Black Sea</td>
<td>Stock assessment inconclusive</td>
<td></td>
<td>There are at least two stocks, Black Sea and Sea of Azov, the latter migrates between the Sea of Azov and the Black Sea. The two stocks are managed separately. Historically different stock components appear to have undergone differing trajectories. Regarding the main Black Sea stock, most of the fishing is conducted by Turkey. The purse seine fleet moves into Georgian waters once the season in Turkish waters is over. Only Georgia actively manages the fishery by annual TAC although minimum landing sizes, closed seasons and minimum landing sizes are applied in other areas. This is through a bilateral agreement made in 2003. In the 1990s the capacity of the Turkish fleet built up to reach a state of unprofitability. Since then new entrants are only licenced on an old-vessel exit policy. There is a limit to tyre and constrain technical creep but other policies (e.g. exemption of fishing vessels from fuel tax) led to encouraging larger engine-capacity. This in turn has led to waste of fuel for no increased catch. A fishing vessel buy-back scheme was introduced in 2012 to try and reduce the fleet capacity. In some years vessels targeting sprat also shift to anchovy if sprat are scarce. High-grading and slippage of catches is reported to be a significant problem in some of the anchovy fisheries. Landings data are supplied by Bulgaria, Georgia, Romania, Turkey and Ukraine but there are no reliable estimates of effort. Fisheries independent surveys are conducted by Turkey for hydroacoustics and egg and larval production but the time-series is not yet long enough to be used in the assessment. A stock assessment was conducted using extended survivors analysis (XSA) but the results are considered highly uncertain. No reference points have been estimated for this stock.</td>
<td>STECF (2013)</td>
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<tr>
<td><em>Engraulis japonicus</em></td>
<td>East China Sea, South China Sea, Yellow Sea</td>
<td>Stock assessment advice either inaccessible or no known assessments conducted</td>
<td></td>
<td></td>
<td>Ricard et al. (2012)</td>
</tr>
<tr>
<td><em>Engraulis mordax</em></td>
<td>California to Mexico</td>
<td>Northern anchovy is a monitored species (as opposed to being actively managed) under the Pacific Management Council. The stock assessment is not updated annually.</td>
<td></td>
<td>Anchovy fisheries are managed under the Coastal Pelagics Species Fishery Management Plan. Landings in 2009 and 2010 were negligible but this may reflect market conditions rather than stock status. No data in RAM.</td>
<td>Cal. Dep. Fish Wild., PMC (2011), Ricard et al. (2012)</td>
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<tr>
<td><em>Engraulis ringens</em></td>
<td>Peru</td>
<td>In recent years stock biomass has had to be revised downwards from egg survey based estimates due to higher than expected juvenile mortality. In 2012 this led to a significant (68%) cut to catch quotas. The stock may be entering a less productive phase.</td>
<td>IFFO, FOS</td>
<td>The fishery is managed under the Ministry of Production (PRODUCE) and the Vice-Ministry of Fisheries. Scientific advice is given by IMARPE (Marine Research Institute of Peru). Stock assessments are based on commercial data and fisheries independent surveys. The long-term management objectives are set by PRODUCE. Management plans seek to reconcile economic growth with environmental outcomes, to enhance trade and investment whilst protecting natural capital and to implement an Action Plan for Sustainability of the Marine Environment which support goals set by the Asian Pacific Economic Co-operation (APEC). The historical patterns in this major stock and recent changes in management designed to control fishing effort are described in other parts of the present report. IFFO assessed the fishery as having high compliance with their RS requirements. Issues noted were lack of detail on violation consequences and lack of controls on impacts on non-target species (particularly Peruvian diving petrel <em>Pelecanoides garnotii</em>). Foodweb interactions are accounted for in the fisheries advice. Recommended catch limits are designed to avoid recruitment overfishing acknowledging the high variability in early life stage survival. At re-certification a number of issues were noted included lack of transparency with assessment methodology, lack of clarity in quota setting and implementation, lack of information on indirect fishery impacts, possible IUU activities, problems with increased discarding of juveniles. Biomass limits have been defined but are not explicitly cited in stock assessment summaries. The Copeinca fishery is listed as certified by FOS but there are no audit reports available (accessed 1 October 2013)</td>
<td>(Hervas 1989), (2009), (Romito 2011b), (Peacock 2012k), (2012a), (IMARPE 2012)</td>
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<tr>
<td><em>Engraulis ringens</em> con/td</td>
<td>Chile</td>
<td>See separate regional summaries below</td>
<td></td>
<td>Fisheries are managed in Chile by the Subsecretariat de Pesca who provide policy settings and regulatory framework, the Servicio Nacional de Pesca are responsible for implementing the policy, for catch sampling and for legal enforcement and the Instituto de Fomento Pesquero (IFOP) and universities conduct research and provide scientific advice. Stakeholder engagement is mainly through the National Fisheries Council which deals with quota splitting, Fisheries and Aquaculture plans and development proposals for small-scale fisheries. There are also five regional fisheries councils who help liaise between the central authority and regional stakeholders. The pelagic commercial sector is subject to annual catch quotas. There is a maximum catch limit per firm (MCLF) system which allows quota trading. Three separate anchovy stocks are recognised and these are assessed independent of each other. Stock assessments are based on catch data and using fisheries independent egg production and acoustic surveys.</td>
<td>Peacock (2012c)</td>
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<td></td>
<td>Regions V-X (Chile)</td>
<td>Stock may be entering a less productive phase and F needs to be restrained.</td>
<td>IFFO, FOS</td>
<td>The IFFO audit recorded a few weaknesses including a lack of recording of by-catch although all the catch is landed. Fisheries Development Institute (IFOP) methodology is not publically available so difficult to evaluate quality of the stock advice. Lack of transparency in quota setting process. Improvements required before re-certification in 2016.</td>
<td>Romito (2010), Peacock (2013c)</td>
</tr>
<tr>
<td></td>
<td>Regions XV-IV (Chile)</td>
<td>Fishery appears generally well managed, some improvements in transparency of the management process needed.</td>
<td>IFFO, FOS</td>
<td>The IFFO audits reported some problems including a lack of recording of by-catch although all the catch is landed. Anchovy is also important for artisanal fisheries and their requirements and fishing effort needs to be incorporated into the management plan. Improvements in transparency of advice setting process are required especially as in previous years quotas in excess of biological advice have been set.</td>
<td>Peacock (2012c), Peacock (2013d)</td>
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<tr>
<td><em>Ammodytidae spp.</em> Sand lance/eels</td>
<td>North Sea Sub-area IV, Division IIIa</td>
<td>Separate advice given for 7 sandeel areas.</td>
<td>IFFO (Denmark)</td>
<td>The fisheries are managed by the EU CFP and Norway on the basis of scientific advice provided by ICES. In the Norwegian EEZ sandeel fisheries are subject to a spatial management plan which also includes provision for temporal controls. However, there is no explicit management plan outwith the Norwegian EEZ. The main management tool applied area catch quotas but localised spatial fisheries closures are also used to limit localised depletion. The main sandeel fisheries are conducted by Denmark and Norway with some localised catchas by UK vessels. Prior to 1995 sandeels in the northern North Sea were assessed separately from the southern North Sea but in 1995 it was decided to merge these into a single stock. Recent modelling work suggests this is incorrect and that there are several self-contained stocks in the North Sea. This led to concerns regarding local depletion and impacts on other ecosystem components such as seabirds. In 2010, the stochastic multispecies simulation model (SMS) was used to provide separate stock assessments for regions 1-3. As well as commercial catch data, fishery independent dredge surveys are conducted in some of the areas and used in the assessments. Estimates for $B_{lim}$ and $B_{msy}$ have been produced for each of these areas. Although sandeel can live for up to 10 y (Table 3), most of the catch is composed of fish &lt; 5 y old. In common with other short lived stocks, $B_{msy}$ trigger has been set at $B_{pa}$. Analytical assessments could not be conducted for the other areas. IFFO considered that the management approach is not entirely consistent with the precautionary approach and IFFO certification only applies to Sandeel Areas 1-3 due to a lack of scientific data for the other areas.</td>
<td>Platt (2010d), Peacock (2011f), (2012h), (2013h), ICES (2013d)</td>
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<tr>
<td><em>Ammodytidae spp.</em> con/td</td>
<td>West Scotland, Division VIa</td>
<td>Unknown</td>
<td></td>
<td>This stock is managed under the EU CFP on advice from ICES. The stock is considered data limited. Advice is provided on a biennial basis. Historically a fishery operated with landings of up to 24.5 Kt but this fell from 1988 to zero in 2005. The fishery has not re-opened. In line with ICES approach to dealing with data limited stocks, current advice is that no catches should be allowed unless there is evidence this will be sustainable.</td>
<td>ICES (2012a), (2012c)</td>
</tr>
<tr>
<td><em>Mallotus villosus</em> Capelin</td>
<td>Canada, Newfoundland and Labrador</td>
<td>Advice is provided on catch, acoustic and larval survey trends and fishers perceptions but formal stock assessment has not been possible.</td>
<td></td>
<td>As with other Canadian fisheries the main management responsibility lies with DFO. The Atlantic stocks are managed under an Integrated Management Plan for NAFO areas 4R/S/T. The fishery is seasonal and opening dates vary with quota management unit. The main management tool is annual TAC which is split between the areas and fleet sectors. To protect salmon there are restrictions on trap-net design. Current impact of predators is not well understood although piscivores have been increasing and harp seals relatively stable. Since 1979 a conservative exploitation rate not to exceed 10% of the projected spawning biomass was advised but this has not been implemented since 2000 due to the inability to predict stock biomass.</td>
<td>Fisheries and Oceans Canada (2013b)</td>
</tr>
<tr>
<td>Canada, Gulf of St Lawrence</td>
<td>No formal stock assessment.</td>
<td></td>
<td></td>
<td>Landings have been increasing but seem relatively stable since 2008. Advice is provided on catch trends and fishers perceptions but formal stock assessment has not been possible.</td>
<td>Fisheries and Oceans Canada (2013c)</td>
</tr>
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<tr>
<td><em>Mallotus villosus</em> con/td</td>
<td>Iceland and West Greenland</td>
<td>Precautionary advice – no fishing</td>
<td>IFFO</td>
<td>A single capelin stock is recognised which migrates between Icelandic and adjacent waters. The capelin stock is managed via a three-party agreement which includes Iceland, Norway and Greenland and part of Iceland’s quota is shared with the Faroe Islands. The main management responsibility for the fishery rests with Iceland. Although 6 ministries are involved the Ministry of Agriculture takes the lead. Fisheries are managed via the 2006 Icelandic Act which gives the Marine Policy a legal basis. The main management tool used is annual TAC but the fishery is spatially closed in response to real-time observations on excessive catches (&gt;20%) of juvenile capelin. The TAC is distributed among vessels under a limited ITQ approach. Stock assessments and research are conducted by the Marine Research Institute (MRI) but ICES also provides stock advice. There is a long-term management plan in place and a B_{lim} reference point has been estimated at 400 Kt. Because of the short life of capelin, B_{msy} targets have remained undefined. The management plan has not been evaluated by ICES in relation to the precautionary approach. Stock assessments are based on acoustic surveys. IFFO certified this fishery as having high compliance although noted some short-comings in reporting ETP interactions. There are anecdotal reports of humpback whales being caught in capelin purse seines. Since 2011 the acoustic index has suggested very low biomass with SSB estimated to be around or just below B_{lim} and so under the harvest control rule no TAC has been set. The last substantial harvest of 747 Kt took place in 2011/12. The present poor stock status may be linked to a rise in sea temperatures in Icelandic waters.</td>
<td>Platt (2010b), Peacock (2012e), (2012f), ICES (2013e)</td>
</tr>
<tr>
<td>Species</td>
<td>Area</td>
<td>Status</td>
<td>Certification</td>
<td>Comments on management and certification</td>
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<tr>
<td><em>Mallotus villosus</em> con/td</td>
<td>Barents Sea and Norwegian Sea</td>
<td>Stock biomass has undergone very strong cycles in the past probably driven by environment and foodweb interactions. Currently SSB is high but recruitment is declining.</td>
<td>IFFO</td>
<td>The Barents Sea capelin fishery has been managed under a bilateral Norwegian/Russian agreement since 1979 via the Mixed Russian-Norwegian Fishery Commission. The main management tools are catch quotas. Separate TACs are set for the autumn and winter fisheries although in recent years little autumn fishing has taken place. The fishery is also subject to a closed season. Acoustic and trawl survey data are used in the assessments which are conducted by ICES. SSB reference points have been defined in terms of B_{escapement}. The stock assessment process takes account of foodweb interactions. Management of the fishery is strongly stake-holder engaged. Declining recruitment in recent years suggests that fishery restrictions will need to be implemented in coming years. There is on-going research to develop multispecies advice due to the importance of capelin in the Arctic and sub-Arctic food-web.</td>
<td>Peacock (2011d), (2012d), (ICES 2013b)</td>
</tr>
<tr>
<td>Species</td>
<td>Area</td>
<td>Status</td>
<td>Certification</td>
<td>Comments on management and certification</td>
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<tr>
<td><em>Euphausia superba</em></td>
<td>Atlantic</td>
<td>Revised stock estimates have increased to 60.3 Mt in Area 48. Current exploitation levels are below precautionary trigger point.</td>
<td>MSC, FOS</td>
<td>The overall responsibility for managing fisheries in the Antarctic lies with CCAMLR. The management regime has already been described more fully in other parts of this report. Reference points for krill harvesting have been defined although estimation of the actual stock abundance remains challenging. Further research on foodweb interactions is on-going. The fishery could be affected if Antarctic marine protected areas are established. The MSC certification of the fishery was controversial and led to objections but was upheld. The main argument for the sustainability is the relatively small catch relative to the estimated available population biomass. Olympic Seafoods and Shagaii Fisheries General Corp. are shown as being certified by FOS for krill but there are no accessible audit reports on the FOS website (accessed 1 October 2013).</td>
<td>Medley et al. (2010), Hough &amp; Medley (2011), (2012), (2013)</td>
</tr>
</tbody>
</table>
5.5. Improving management of SPF stocks

5.5.1. Requirements at the global level

With regard to the previous State of World Fisheries and Aquaculture (SOFIA) report (FAO 2010c), (Pauly and Froese 2012) were critical of the use of the word “stability” in relation to global catch trends. A “relatively stable”, or “slightly declining” trend (depending on your interpretation) is also apparent in the global SPF landings (Figure 1) but, as pointed out by Pauly and Froese, this takes no account of changes in fishing effort. Measured in terms of kilowatt days, Pauly and Froese (2012) presented data to show that global fishing effort has increased by 25% between 1980 and 2010 (~3 x 10^9 kilowatt days to ~4 x 10^9 KWd). This increasing trend is linear across the last decade and mainly driven by expansion of fleets in Asia. This observation has led to further analyses of China’s fishing operations (Pauly et al. 2013) which demonstrated potential under-reporting of distant water catches by 4.2 Mt y⁻¹ to FAO. Chinese fleets now operate globally (Mallory 2013), much like the fishing operations of the former Soviet Union which also landed large amounts of SPF. In SOFIA 2012 (FAO 2012), the word “stability” was not used in relation to the landings trends but neither wasn there any additional analysis of landings in relation to fishing effort, apart from some general comments in the text. FAO should consider including analysis of catch trends in relation to available effort data (Mullon et al. 2005). With regard to SPF, CPUE data must be interpreted cautiously because schooling can lead to changes in catchability as a stock declines (Pikitch et al. 2012a).

Pauly and Froese (2012) also suggested that data held in FishStat is increasingly unreliable giving some examples of where “reconstructed” catches are significantly different from “official” reported landings. This seems to be supported by evidence in SOFIA(2012) itself which shows substantial proportions of countries failing to return adequate catch data for 2009 (Table 2 in FAO (2012)). Among developed countries the proportion failing was ~24% and in developing countries it was 61%. In face of this one can only reiterate the comment from Garibaldi (2012):-

“To this end, national data collection systems have to be improved in those countries where they are weak, not operating regularly, or even not present at all. Efforts should be also made at the national level to avoid inconsistencies between data compiled by different institutions and to avoid reporting of catches linked to national plans rather than actual data. Lastly, FAO should cooperate continuously with national institutions to reduce as much as possible the still high percentage of non-reporting countries.”

With regard to SPF in particular, the recommendation to improve recording of the sources of fishmeal and fishoil (i.e. to discourage use of the “fishmeals nei” category) has already been discussed 4.2.2. Tracking the amounts of fish needed to produce products such as fishmeal can act as a useful check against reported SPF landings. However, this is only really meaningful if the sources of the raw material are recorded.

Data and reports cited in section 5.3 clearly show a very uneven pattern in the quality of SPF fisheries management globally. While many of the major stocks, including Peruvian
anchovy (*E. ringens*), Atlanto-Scandian and North Sea herring (*C. harengus*) are being relatively well-managed, many others requiring re-building or have highly uncertain status. Lack of data for fisheries in the Pacific and Indian Oceans is particularly troubling given the increases in landings which seem to be taking place in those regions and reports that many fisheries in these regions are essentially un-regulated.

Increasing numbers of SPF fisheries are subject to some form of external sustainability certification. This is generally a positive trend although the standards applied by different schemes vary and this in itself is giving rise to vigorous argument in the scientific press and media. Perhaps the greatest problem with current certifications is the dominance of large fisheries and the lack of evidence that certification is helping drive improvements in smaller fisheries and particularly in developing countries.

Resources available for research and management also vary strongly with the economic value of the stock. Although the data intensive fisheries management approaches developed mainly in Europe and North America can perform well for SPF stocks, it is clear that these methods may not be transferable to many smaller stocks, or to developing countries (Caddy and Mahon 1998, Caddy 2002). Further research and workshops to discuss the optimal management of smaller SPF stocks in developing countries are urgently needed as is the dissemination and sharing of information and training on best practice. A stronger evidence base on the effectiveness of fisheries co-management in developing countries is required (Evans *et al.* 2011). Developing effective EAFM for inshore fisheries also means engaging with a wide range of issues beyond stock biology including political, educational, gender, governance and property rights (Andrew and Evans 2009, Perez *et al.* 2010).

**5.5.2. Requirements at the stock level**

The basic data requirements for providing fisheries advice are well understood. At a minimum reliable recording of catches to species level and records of fishing effort, preferably spatially resolved are needed. This should allow the estimation of limit reference points and fitting of relatively simple depletion-based stock assessment models although these may not be appropriate for very short-lived species such as anchovies. Trends in CPUE must be treated with great caution as fisheries often exhibit hyper-stability and this can be particular true for shoaling species (Cardinale *et al.* 2009). If changes in the spatial patterns of the fishery are known then hyper-stability can be corrected for but if spatial data are not available, changes in un-corrected CPUE can be very mis-leading (Rose and Kulka 1999, Harley *et al.* 2001, Walters 2003, Cardinale *et al.* 2009).

For longer-lived SPF such as herrings and sardines, age-based assessment models may be appropriate but this requires additional sampling for maturity and for production of weight-at-age keys. As well as allowing the conversion of catch weights to catch-at-age which is required for model input, these data are useful for examining changes in fish weight, condition and maturation over time. All these changes can potentially impact reference points so should be tracked over time (Rahikainen and Stephenson 2004). Additional studies on ageing errors may also be needed as these can significantly affect aged-based stock assessment as seen in Pacific sardine (PMC 2011). If there is significant discarding in the
fishery this can also lead to serious problems in stock assessments if the landings data are assumed to reflect total catches. However, for most SPF fisheries discarding is not usually thought to be a major issue (Table 17). Collection and quality control of fisheries-dependent data is itself a challenging task and one which requires to be adequately resourced. In addition to the fisheries-dependent data, some form of fisheries-independent data will also often be required to tune the assessment model. There are numerous stock assessment models available and discussion of these is beyond the scope of this review (Hilborn and Walters 1992, Quinn and Derison 1999, Walters and Martell 2004b). However, they all tend to be sensitive to decisions regarding the relative weighting of the different input data and if there are divergent trends this will also cause problems.

Concern has been raised about the burgeoning costs and complexity of the advice process in developed countries with suggestions that cheaper indicators may be adequate (Caddy 2002, Cotter et al. 2004, Kelly and Codling 2006). However, the consequences of adopting these approaches have not been fully explored although they are already applied de facto to many data-limited stocks within Europe (ICES 2007). Other fishery-dependent data can also be very useful for generating fishers perceptions of stock trends, tracking changes in spatial patterns and fishing practices, developing more selective fishing gears etc. (Mackinson et al. 2011). Participation by fishers in research and data collection can deliver real advantages but effective implementation of such schemes is not without difficulty. Fishers often require financial incentives to take part in sampling schemes, particularly if data collection will slow their normal fishing practices (Lordan et al. 2011). Significant effort may also need to be expended in training and the time horizons involved in making scientific advances are also often not appreciated (Mackinson et al. 2011). Issues of fishers’ data confidentiality, for example around vessel monitoring systems, also have the potential to drastically impede research needed to deliver EAFM (Hinz et al. 2013). For these reasons there is increasing emphasis on co-working and co-management and, although this can be challenging, it should ultimately produce better managed fisheries (de Vos and Mol 2010, Evans et al. 2011) (Lordan et al. 2011). Skills for developing co-management are however often lacking in traditional fisheries science agencies so much stronger links with social scientists and practitioners need to be developed. In some countries the costs of delivering fisheries advice are at least partially funded through levies on the fisheries (Harte 2007) whilst in others they are wholly state-funded. There is a considerable literature examining the relative merits of different funding models which is beyond the scope of this review but having adequate long-term sources of funding is essential for effective fisheries management.

Data collection for traditional fisheries stock management often stops at this stage but EAFM suggests further information is needed. This will include studies of the diet and predators to allow foodweb models to be developed. It is unlikely that it will be practical to update these data very often but collection during different productivity regimes can be helpful (see section 3.3.2). In some cases changes in abundance of SPF in predator diets may provide advance warning of changes in stock productivity before signs are seen in fisheries catches (Velarde et al. 2013). Such indicators can be available from separate research programs run by universities and non-governmental organisations so fisheries scientists and
managers need to be aware of the wider range of research being undertaken in their ecosystem, rather than just focusing on the biology of their target species.

Oceanographic data can often be used to inform assessments and management even if the data are not formally included in stock assessment models. For example, all ICES stock assessments are now required to comment on whether oceanic conditions may be affecting the stock status. With regard to the major SPF stocks, nearly all assessments include some consideration of prevailing environmental conditions because of the impacts on SPF recruitment and distribution (see section 3.5) Collection of oceanographic data has traditionally been the preserve of government agencies and universities but there is great scope for more involvement of fishers. New cheaper automated systems for recording and reporting environmental parameters are becoming available and could greatly increase the quantities of high-quality data available (Nicol et al. 2013). Unfortunately these systems largely apply to the collection of meteorological and physical data such as sea temperature, salinity and fluorescence. With regard to monitoring SPF prey there has been some progress with developing automated systems for identifying and quantifying plankton (Irigoin et al. 2009, Gorsky et al. 2010, Lelièvre et al. 2012) but, because of current limitations, expensive and time-consuming microscopic analysis is usually also required. The Continuous Plankton Recorder Survey run by Sahfos (Plymouth, UK) reduces costs somewhat by deploying samplers behind ships-of-opportunity such as ferries. The sampler design has its origins in work by Sir Alistair Hardy on the relationship between herring (C. harengus) and zooplankton in the North Sea (Batten et al. 2003, Reid et al. 2003a). CPR data have provided the basis for some of our most comprehensive analyses of ecosystem-level changes in plankton community structure, abundance and phenology (Planque and Taylor 1998, Beaugrand et al. 2002, Reid et al. 2003b, Beaugrand and Ibanez 2004, Edwards and Richardson 2004, Beaugrand et al. 2007). Although survey coverage is highest in the North Atlantic, the long-term plan is for significant expansion. Additional routes are slowly being added including important regions for SPF such as the Bay of Biscay, Benguela Current, and the southern Ocean (Sahfos 2012).

Alternate management approaches, such as marine protected areas (MPAs), have been widely promoted within EAFM as providing insurance against over-exploitation (Pérez-Ruzafa et al. 2008). For pelagic species MPAs may however be less effective since most SPF stocks are mobile over large areas (Le Quesne and Codling 2009, West et al. 2009). Spatial fisheries closures are used in some SPF fisheries but generally to protect against local resource depletion for the benefit of predators such as seabirds (Daunt et al. 2008, SGSSI 2012). Spatial fisheries closures or gear restrictions may however be beneficial for conserving some coastal SPF stocks, particularly where fisheries target localised spawning aggregations. An example is the small, spring-spawning Thames herring (C. harengus) in the North Sea where trawling over the inshore spawning grounds is banned although a limited drift-net fishery is permitted (Roel et al. 2004).

Data and analysis of the social and economic aspects of SPF fisheries are also required for EAFM in order to explore how the whole system may respond to changes in stock productivity, prices, markets and management policies (Frid et al. 2005, Aranda 2009,
Mullan et al. 2009, Shepherd and Jackson 2013). Particularly in developing countries and with smaller SPF stocks, co-management approaches may prove more effective although the evidence base to prove this is rather limited (Evans et al. 2011).

5.5.3. Improving management of data-poor stocks (DPS)
The costs and practical difficulties of delivering fisheries advice based on modern mathematical modelling approaches have already been mentioned several times. While the resources required are probably justified for large, economically important SPF stocks, such as Peruvian anchovy and Atlanto-Scandian and North Sea herring, it does not seem practical to deliver similar levels of advice for all stocks (Froese 2004) Caddy 2002, Kelly & Codling 2006). Data-poverty arises for many reasons including in stocks which are low-value, fisheries in countries lacking the resources to undertake monitoring, fisheries where a wide mix of species which are difficult to identify are harvested, fisheries in countries where governance is lacking or dysfunctional, fisheries which are in dispute with management and fisheries where there is substantial IUU activity. Even in well-resourced countries a large proportion of stocks lack formal assessments, for example in California this fraction has been estimated at around 70% (Honey et al. 2010). At present within ICES advice on such stocks tends to be presented using precautionary-based language but the advice often defaults to status quo catches (ICES 2010). Although there are other reasons why stocks lack assessments, data-poverty will be the reason for a significant proportion. Alternate approaches for managing data-poor stocks are therefore urgently required. Despite several recent workshops, working groups and research programs, progress on this topic has been limited. This is presumably because the majority of research resources remain focussed on the major managed stocks. It is also important to note that data-poor stocks are not necessarily small-stocks, although the proportion of DPS among small-stocks is likely to be higher.

A number of strategies for managing DPS have been proposed. For example (Honey et al. 2010) describe a framework which attempts to structure available approaches against data-richness. Note here that there can also be stocks which are data-rich but information-poor - there is a lot of data available but for various reasons it actually contains little reliable information. There are numerous reasons this can arise but typical causes are mis- and under-reporting, data not resolved to appropriate taxonomic levels, data which only covers part of the fishery, data which only covers part of the fishes’ distribution which is often a problem with migratory species (MacCall 2012).

Australia has developed considerable experience in assessing DPS due to recent changes in its fisheries legislation. Punt et al. (2011) describe some of the approaches taken. Advice for DPS generally falls into two approaches (i) to use empirical decision rules (ii) to group stocks and conduct common assessments assuming that all stocks in the group have similar dynamics. Empirical decision rules generally revolve around developing some indicator of stock status and fishing pressure and tracking how these change over time. If the trend breaches some limit then this should trigger some management response. This approach is very similar to the use of harvest-control rules discussed earlier but the thresholds and targets are not set separately for every individual species and stock (Smith et al. 2008). The
use of indicators has parallels with developments in EBM where regional-scale indicators are being proposed to summarise changes in the overall state of marine ecosystems (Bundy et al. 2010). While some proposed EBM indicators incorporate outputs from model-based stock assessments (Gascuel et al. 2013), others rely more on observational data e.g. landings records and fisheries surveys (Purwanto 2003, Blanchard et al. 2010, Jouffre et al. 2010, Shin et al. 2010, Greenstreet et al. 2012b). For DPS observational data will generally be the only available source but can potentially be used to provide useful indicators (Froese 2004). However, the performance of single-species and ensemble-indicators is still being investigated and many questions remain as to how they respond to changes in the state of stocks and to pressures, including climate (Cury et al. 2005).

) and fishing (Hall and Mainprise 2004b, Piet et al. 2007, Greenstreet et al. 2012a). The alternative of performing stock assessments by group has the disadvantage that any data which are available for the DPS tends to get ignored (Punt et al. 2011). However, given that information may be available for other species being fished by the fishery, Punt et al. (2011) provided examples of how this knowledge could be used to inform multi-stock assessments for the DPS components of the catch. Prior information on life history parameters, for example from FishBase, other assessments or empirical relationships, can also be fed into Bayesian models for estimation of sustainable yields for DPS (Dick and MacCall 2010). Given that responsive and meaningful indicators can be developed for DPS fisheries, the results still need to feed into effective management systems, as described in earlier sections. Without effective feedback into management one is simply observing the changes in stock status. For dealing with DPS (Honey et al. 2010) propose the following steps:-

1. **Assess the data-richness** Identify and evaluate the data available, take account of wider sources of information such as FishBase. Take account of the scale of the fishery, stakeholder interests, cost-benefits of present data collection. Use of a qualitative score-card can help, examples are shown in (Honey et al. 2010). Their examples lack some of the considerations shown in Table 17, particularly with regard to foodweb and ETP interactions but they emphasize that managers should develop their own score-cards appropriate to their stocks rather than simply copying the examples given.

2. **Use this assessment to evaluate analytical options** Link the analysis of the available data-richness with the potential analytic options shown in Table 19. Fuller descriptions of the various approaches are given in Honey et al. (Honey et al. 2010) and references cited therein.

3. **Apply the appropriate method** As well as data richness, available expertise, time and analytical resources will determine which method can be applied. Cost-benefit trade-offs also need to be taken into account given that many DPS will be low-value. Other EAFM considerations may affect which methods should be used, for example although the fishery may be small it could be having a high impact on other species of
4. Use the resulting information

Having produced an assessment of the stock status and likely prospects this information must be used to manage the fishery (even if the advice is just to maintain the status quo).

### Table 19: Analytic options for data-poor stocks

<table>
<thead>
<tr>
<th>Option class</th>
<th>Approach</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fishery evaluation methods</td>
<td>Sequential trends</td>
<td>Use of environmental proxies Yield per recruit analysis Fractional change in egg production In-season depletion Depletion-corrected average catch</td>
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<tr>
<td></td>
<td>Vulnerability analysis</td>
<td>Taxa productivity and susceptibility analysis based on general life-history traits or other stocks</td>
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<td></td>
<td>Extrapolation</td>
<td>“Robin Hood” approach</td>
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<tr>
<td>Decision making methods</td>
<td>Decision trees</td>
<td>Length-based reference points Simulation studies of robustness and consequences of management options</td>
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<td></td>
<td>Management strategy evaluation (MES)</td>
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</table>

In conclusion it is important to re-iterate that little useful advice for data-poor stocks can be provided unless at least some reliable data are being collected on catches but that given such data collection, it is quite feasible to improve the management of DPS fisheries (Pikitch et al. 2012a).
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