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Mass occurrence of *Salpa fusiformis* and records of the rare salps *Cyclosalpa bakerii* and *Thetys vagina* from northern Scotland

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Gelatinous zooplankton including salps are an important but often overlooked component of marine ecosystems. This study documents a bloom of Salpa fusiformis *at five locations to the north of mainland Scotland. The bloom was observed at Sula Stack, Sula Sgeir, North Rona and at two other locations to the west coast of the Orkney Islands. Salp blooms have the potential to deplete phytoplankton biomass, impacting on other zooplankton, including copepods and fish larvae. New records of two rare salps* Cyclosalpa bakerii *and* Thetys vagina *are also documented from North Rona and Skirza Head, Caithness. These specimens were observed in the aggregate (sexual) form. These observations represent the second record in the UK of* C. bakerii *and the third and fourth records of* T. vagina.

Keywords: salp, *Thetys vagina*, Scotland, Thaliacea, gelatinous zooplankton, *Salpa fusiformis*, *Cyclosalpa bakeri*, Orkney, Sula Sgeir, North Rona

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INTRODUCTION

Gelatinous zooplankton including salps (order Salpida) are an important but often overlooked component of marine ecosystems (Andersen, 1998; Mills, 2001). Salps have a complex life history with alternation of generations between aggregated sexual blastozooids (aggregate form) and solitary asexual oozooids (solitary form). The sexual and asexual forms are so different that early taxonomists categorized them as different species until their life cycles became known (Fraser, 1981).

Salps can form extremely dense populations in the form of blooms or 'swarms' several kilometres in diameter (Raymont, 1983; Bathmann, 1988). Under favourable conditions, blooms can form rapidly, aided by their ability to reproduce both sexually and asexually and their high feeding capacities, amongst the highest in the metazoans (Madin & Purcell, 1992; Bone, 1998). In high concentrations they can effectively graze phytoplankton stocks within a few days (Deibel, 1982). They are able to feed on particles of a wide size range, from bacteria to microzooplankton (Silver & Bruland, 1981; Caron *et al*., 1989; Kremer & Madin, 1992), and by removing all available food they can exclude other zooplankton groups (Alldredge & Madin, 1982). This can influence the seasonal development of copepod populations through both direct grazing pressure and competition for prey species (Makarov & Solyankin, 1990; Paffenhofer *et al*., 1995; Dubischar & Bathmann, 1997), influencing the structure of the whole pelagic community (Bathmann, 1988).

Salps are widely distributed in oceanic waters, including those of the western Atlantic. They are not considered to be indigenous to British waters as it is thought that they cannot survive the winter (Fraser, 1981); however, they can form ephemeral populations carried with influxes of oceanic waters to the British coast and as such are considered to be good indicators of oceanic water movements (Russell, 1935; Fraser 1949, 1969; Reid *et al*., 2003).

There are 11 species of salp recorded in or adjacent to UK and Irish waters, all of which are in the family Salpidae (Fraser, 1981). The family Salpidae is made up of two sub-families – Salpinae and Cyclosalpinae. The most commonly observed salp in British and Irish waters is *Salpa fusiformis* (Cuvier, 1804), which is a member of the sub-family Salpinae. Mass occurrences have been observed in the North Sea (Reid *et al*., 2003), Ireland (Bathmann, 1988), Scotland and Norway (Murray & Hjort, 1912; Hardy, 1923; Fraser, 1949, 1969; Brattstrom, 1972). Mass occurrences of *S. fusiformis* in the North Sea have been linked to variations in the North Atlantic Oscillation (Reid *et al*., 2003).

The largest species of the salpidae is *Thetys vagina* (Tilesius, 1802), also a member of the sub-family Salpinae, which reaches >230 mm in total length (TL) in the solitary asexual form and 250 mm TL in the aggregate sexual form (Metcalf, 1918; Fraser, 1981), although individuals up to 300 mm have been found in Hawaii (Nakamura & Yount, 1958). Records of T. vagina are sparse and it is typically observed at low densities in all oceans (Hubbard & Pearcy, 1971; Ensal & Daponte, 1999). Whilst this species is most commonly observed in warm oceanic waters, there are a small number of records from colder zones (McAlice, 1986; Sims, 1996; Van Soest, 1998; Iguchi & Kidokora, 2004). There are two known records from UK waters; from St Kilda, Scotland in 1996 (Sims, 1996) and from Wick, Scotland in 1929 (Thompson, 1948). There is also one record from the western Irish Sea (Fraser, 1961). Given the

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paucity of records, this species is considered to be extremely rare in British waters.

Within the sub-family Cyclosalpinae there are five species found adjacent to UK waters; however, only *Cyclosalpa bakeri* (Ritter, 1905) and *Helicosalpa virgula* (Vogt, 1954) have been observed within the UK (Fraser, 1961), with the only record of *C. bakeri* from Scotland.

In this study a mass occurrence of salps from north Scotland is documented and records provided of the diversity of gelatinous zooplankton at some of most remote islands in Scotland.

MATERIALS AND METHODS

Sampling was undertaken during two surveys, a one-day survey of the north coast of Caithness and a six-day survey across the islands of the north coast of Scotland, Figure 1. The Caithness survey was undertaken from the ridged inflatable boat 'North Coast Explorer' on 27 September 2009 as part of the Seasearch dive programme. The survey of the islands of the north coast of Scotland, incorporating the Orkney Islands, Sula Stack, North Rona and Sula Sgeir, was undertaken from the MV Halton from 28 July 2013 to 2 August 2013. Sampling schedule and locations are shown in Table 1 and Figure 1.

Surveys were undertaken using SCUBA from a maximum depth of 30 m to the surface, with the diversity and abundances of benthic and pelagic organisms recorded. Each survey lasted a maximum of 60 min. Species and abundance estimates were recorded *in situ*, with photographic records made of all specimens using a Nikon D300 and D600, Nikkor 105 mm macro and Tokina 10–17 mm lenses with Ikelite housings and Inon Z240 flash units. Pelagic observations were made throughout the full water column; however, abundance estimates were made in three replicate counts of 30 cm^3 at 6 m depth. Photographic records of abundance were made at each location. Temperature at 6 m depth was also recorded using an Apeks Quantum dive computer. Reference specimens were collected for microscopic examination. For gelatinous zooplankton, identification keys by Russell (1953, 1970), Fraser (1981) and Kirkpatrick & Pugh (1984) were utilized.

Table 1. Sample station locations from Caithness, Orkney, Sula Stack, Sula Sgeir, North Rona, Scotland.

Station	Location	Position	Date
C1	Skirza Head, Caithness	58°36′N 03°03′W	27/09/09
O1	Nipple Rock, Orkney	58°56′N 03°22′W	28/07/13
SS1	Sula Stack	59°01′N 04°30′W	28/07/13
NR1	North Rona	59°07′N 05°49′W	29/07/13
NR2	North Rona	59°07′N 05°49′W	29/07/13
NR3	North Rona	59°07′N 05°49′W	30/07/13
NR4	North Rona	59°07′N 05°49′W	30/07/13
SG1	Sula Sgeir	59°06′N 06°09′W	31/07/13
SG2	Sula Sgeir	59°06′N 06°09′W	31/07/13
O2	Swona, Orkney	58°45′N 03°03′W	02/08/13

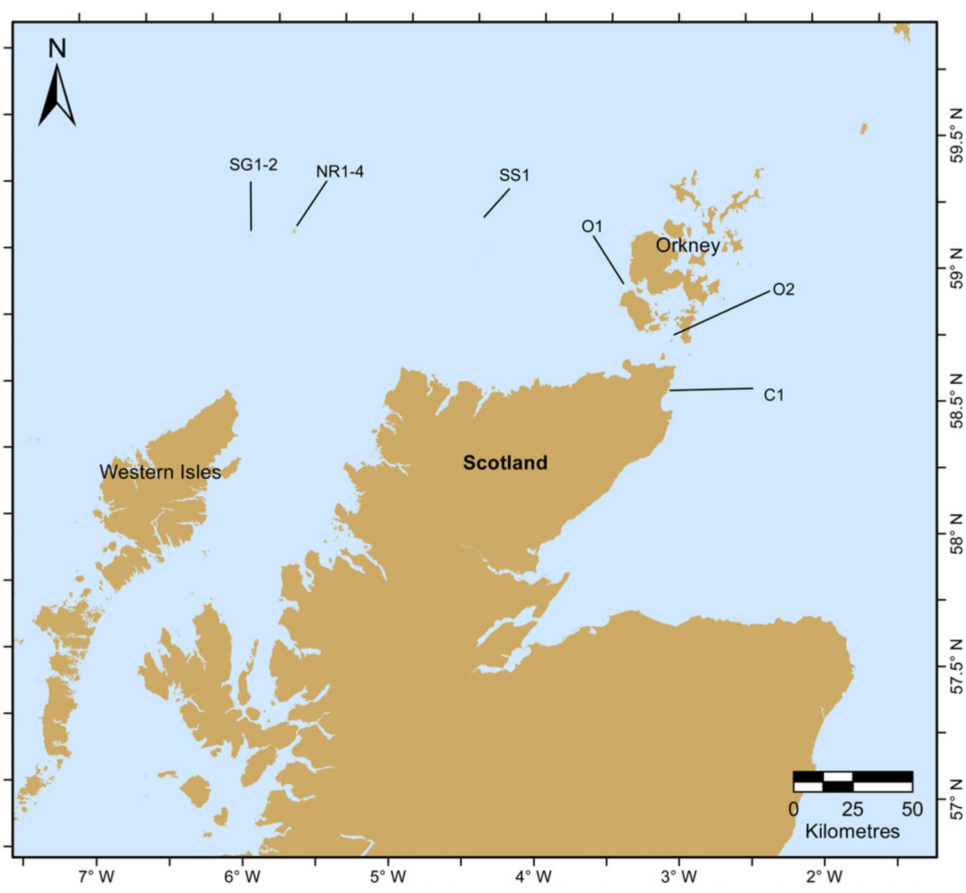

Fig. 1 - Colour online

Fig. 1. Sampling locations, Scotland: C1, Caithness; O1, O2, Orkney Islands, SS1, Sula Stack; NR1–4, North Rona; and SG1–2, Sula Sgeir.

Table 2. Gelatnous zooplankton species observed at sample station locations in Caithness, Orkney, Sula Stack, Sula Sgeir, North Rona – Scotland.

Station	Temperature (°C)	Depth (m)	Salps	Abundance (Ind m^{-3})*	Other gelatinous zooplankton
C1		8	*Thetys vagina*[a]	–	None noted
O1	12.5	26	*Salpa fusiformis*[s,a]	<1	*Aequorea forskalea, Cosmetira pilosella, Aurellia aurita, Cyanea capillata, Beroe* spp., *Pleurobrachia pileus*
SS1	12.6	28	*Salpa fusiformis*[s,a]	>250	*Aequorea forskalea, Cosmetira pilosella, Neoturris pileata, Beroe* spp., Unidentified Cydippida
NR1	12.8	22	*Salpa fusiformis*[s,a]	>250	*Aequorea forskalea, Cosmetira pilosella, Neoturris pileata,* Unidentified Cydippida
NR2	12.8	18	*Salpa fusiformis*[s,a]	>250	*Aequorea forskalea, Cosmetira pilosella, Neoturris pileata,* Unidentified Cydippida
NR3	11.2	17	*Cyclosalpa bakeri*[a] *Salpa fusiformis*[s,a] *Thetys vagina*[a]	>250	*Aequorea forskalea, Cosmetira pilosella* , Unidentified Cydippida
NR4	12.9	21	*Salpa fusiformis*[s,a]	>250	*Cosmetira pilosella, Neoturris pileata,* Unid Cydippida
SG1	12.2	28	*Salpa fusiformis*[s,a]	>250	*Aequorea forskalea, Cosmetira pilosella, Neoturris pileata, Pelagia noctolena,* Unidentified Cydippida
SG2	12.3	30	*Salpa fusiformis*[s,a]	>250	*Aequorea forskalea, Cosmetira pilosella, Pelagia noctolena,* Unidentified Cydippida
O2	11.8	7	*Salpa fusiformis*[s,a]	<1	*Cosmetira pilosella, Neoturris pileata, Pleurobrachia pileus, Beroe spp.,* Unidentified Cydippida

s = solitary asexual form.
a = aggregate sexual form.
*Estimated abundance of *Salpa fusiformis* recorded at 6 m depth.

RESULTS

During the 2013 survey, large numbers of *Salpa fusiformis* were observed at all sampling stations (Sula Skerry, Sula Sgeir, North Rona and west coast of Orkney) (Table 1). *In situ* observation noted that the highest abundances were in the top 10 m but abundances were highly spatially variable, with salps aggregating in gullies and reef areas. Both aggregate chains of sexual individuals (Figure 2) and solitary asexual individuals were observed (Figure 3). Aggregate chains of up to 35 individuals were observed, many of which had young embryos growing within the cloacal chamber. Highest abundances estimates at 6 m were observed at stations SS1, NR1-4 and SG1-2 with abundances estimated to be exceeding 250 indm^{-3} (Figure 4). Abundances at stations O1 and O2 were estimated to be less than 1 indm^{-3}.

The aggregate chains were observed to be easily broken up, and some aggregate forms of *Salpa fusiformis* were observed to

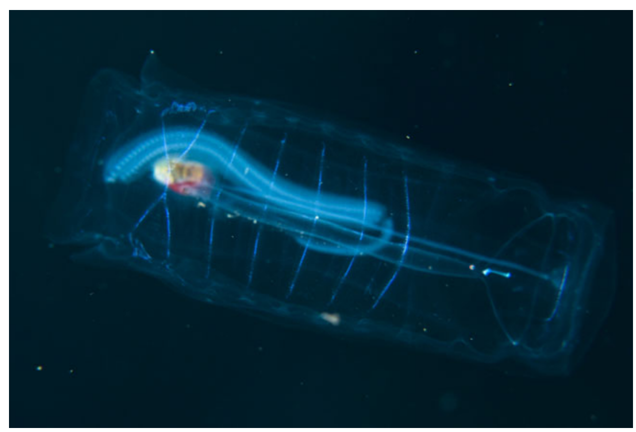

Fig. 3 - Colour online

Fig. 3. Example of *Salpa fusiformis* (oozooids or solitary form), Sula Sgeir, 31 July 2013.

Fig. 2 - Colour online

Fig. 2. Example of *Salpa fusiformis* chain (blastozooids or aggregate form), North Rona, 29 July 2013.

Fig. 4 - Colour online

Fig. 4. Example of photographic record of gelatinous zooplankton abundance (species *Salpa fusiformis*), North Rona, 29 July 2013.

Fig. 5. Example of *Sagartia elegans* consuming *Salpa fusiformis*, Sula Sgeir, 31 July 2013.

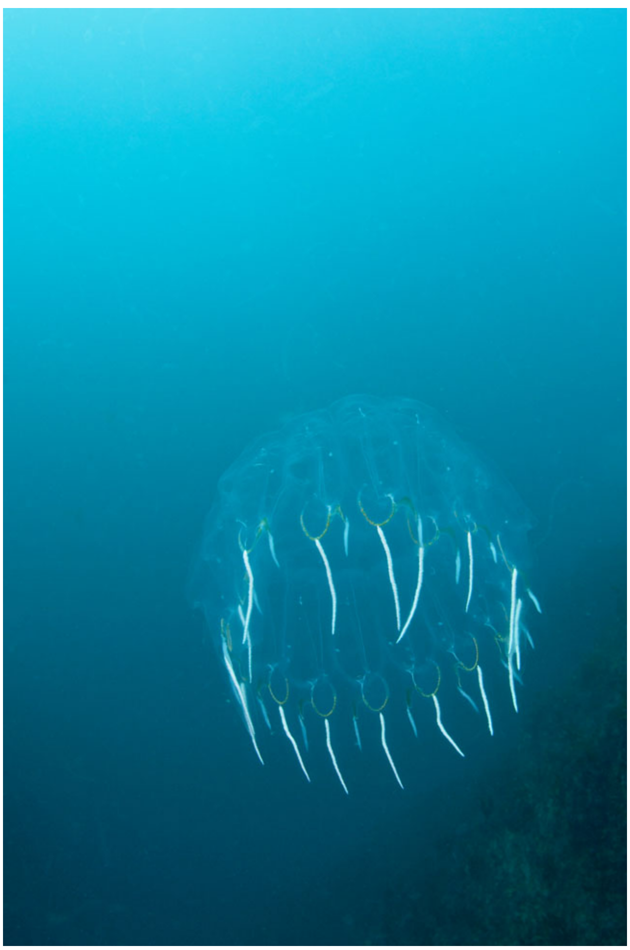

Fig. 6. *Cyclosalpa bakeri* chain (blastozooids or aggregate form), North Rona, 29 July 2013. Image courtesy of Matthew Doggett.

be separated from their chain. Benthic anthozoa, including *Sagartia elegans* (Dalyell, 1848) and *Actinia equina* (Linnaeus, 1758), were observed to be actively feeding on *Salpa fusiformis* (Figure 5).

The salp *Thetys vagina* was observed at station NR3, North Rona on 30 July 2013. The species was the aggregate form with four individuals observed in the chain. The aggregate form of *T. vagina* was also observed on 21 September 2009 at station C1, Skirza Head, with two individuals in the chain (Figure 6). *Thetys vagina* was observed to be actively swimming on both occasions.

Fig. 7. *Thetys vagina* (blastozooids or aggregate form), Skirza Head, Scotland, 27 September 2009.

The salp aggregate form of *Cyclosalpa bakeri* was observed at North Rona on 30 July 2013 (Figure 7). Fifteen individuals were observed in a circular chain.

Other gelatinous zooplankton observed during the survey period included the scyphomedusae *Pelagia noctiluca* (Forsskål, 1775), *Aurelia aurita* (Linnaeus, 1758) and *Cyanea capillata* (Linnaeus, 1758), and the hydromedusae *Neoturris pileata* (Forsskål, 1775), *Cosmetira pilosella* (Forbes, 1848) and *Aequorea forskalea* (Péron & Lesueur, 1810). The Ctenophore *Pleurobrachia pileus* (Müller, 1776) and *Beroe* spp. were also observed.

An unidentified Cydippida ctenophore was observed with the salp bloom at all survey stations in 2013. The ctenophores were 50–70 mm in length had equal length comb rows, which extended from the aboral end to approximately half way along the body to the openings of the sheaths where two tentacles exit (Figure 8). Parasitic copepods were observed on the ctenophore but these were not identified.

Fig. 8. Unidentified Cydippida ctenophore, Scotland, July 2013.

DISCUSSION

In this study, a bloom of the salp *Salpa fusiformis* is documented in the north of Scotland. High density salp blooms have the potential to deplete the phytoplankton stock (Bathmann, 1988), converting small particles into rapidly sinking faecal pellets (Madin, 1982), outcompeting other zooplankton and larval fish (Fraser, 1961; Alldredge & Madin, 1982; Bathmann, 1988). In the areas where the bloom forms, salps can influence the seasonal development of copepod populations (Makarov & Solyankin, 1990; Paffenhofer *et al.*, 1995; Dubischar & Bathmann, 1997) and the structure of the whole pelagic community (Bathmann, 1988). However, the advection of salps to coastal waters, away from areas where the bloom was initially formed, can stimulate primary production due to nitrogen excretion by salps through metabolic processes (Alcaraz *et al.*, 1998) and through their disintegration (Fraser, 1963). The resulting release of nutrients can stimulate the production of phytoplankton and, therefore, increase zooplankton abundance. This process has been linked to increased productivity in the herring fishery in Shetland (Fraser, 1963).

The observations of two rare species of salp in this study, *Thetys vagina* and *Cyclosalpa bakeri*, extend the known range of these species. Including the two observations of *T. vagina* presented in this study, all four records of *T. vagina* in UK waters come from the north of Scotland (Thompson, 1948; Sims, 1996), a comparatively remote area which is subject to limited survey efforts. Whilst the records in this study could indicate an increase in the number of *T. vagina* being transported into UK waters, possibly as a result of climate change, it is perhaps more likely that the low level of survey effort means that this species is under recorded.

There is only one previously known record of *Cyclosalpa bakeri* in UK waters (Fraser, 1961), however, this single record of *Cyclosalpa bakeri* has been questioned by Van Soest (1974), suggesting it could be *Cyclosalpa foxtoni* which was not described until 1974. The observation of the chain in this study, therefore, represents either the first or second record from the UK.

The unidentified Cydippida ctenophore is a species that is not identified by Greve (1975) as present in British waters. The observation of this unknown Cydippida and the two rare salps illustrates the paucity of knowledge of the oceanic gelatinous zooplankton around the British coast, particularly offshore. Despite the high density of salps observed in this study, their presence would have gone undocumented had it not been observed on this expedition. There has been increasing effort to develop models to understand the variations in economically important fish species, however, these models often exclude the effects of plankton fluctuations which have the potential to significantly impact recruitment, particularly in the North Sea (Reid *et al.*, 2003). Without more detailed study of the natural variability in zooplankton abundance and their drivers, our understanding of the systems that influence higher taxa is likely to remain incomplete.

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