The origins of aquaculture

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Zooarchaeology
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Subheading: Measurement comparisons of ancient and modern carp pushes back the initial stages of aquaculture to 6000BC, raising the possibility that rice paddy and fish coculture systems are much older than previously thought. This research suggests carp were later independently domesticated twice, once in Europe and once in Asia.

Common carp, *Cyprinus carpio*, are the earliest truly domesticated fish[1], and the third most productive farmed fish today[2]. Despite their modern value, questions surround their wild origins, the process by which they became used for aquaculture, and the date and location of subsequent domestication. The wild ancestor of the common carp was present in two regions, an eastern population in China, Laos and Vietnam, and a western population in the Black, Caspian and Aral Sea drainages[3], [4]. Writing in this issue of Nature Ecology & Evolution, Nakajima and colleagues use a combination of archaeological fish remains and modern carp raised in a traditional rice paddy field to show that the earliest evidence for carp aquaculture comes from China[5].

In the Asian rice and fish co-culture system, common carp are raised alongside rice plants in an ecologically sustainable and mutually beneficial relationship. Modern trials of traditional methods show greater stability of rice yields and reduced need for fertilisers and pesticides compared to rice monoculture. Carp naturally eat and uproot weed species, and eat insect pests all while providing natural fertiliser[6]. In turn, insects attracted to the rice provide food for the carp, the shade provided by the rice reduces temperature extremes, and the rice absorbs fish waste and reduces concentrations of ammonia[7]. Long-term sustainability and stable production of both rice and fish are therefore possible without intensive fertiliser use. Modern aquaculture will soon produce half of the world's fish supply, with resulting environmental degradation, loss of biodiversity and non-native invasions[8], but fish-rice co-culture systems continue a long tradition of sustainable farming without these problems. Historical records and archaeology show carp were raised in rice paddy fields during the first millennium BC. However, such fields predate those records by another four millennia, which led Nakajima et al to ask when and where carp started to be raised in managed ponds. Archaeological fish bones provide one way of trying to answer this question.

Zooarchaeology is the study of past human interaction with animals, using identification and analysis of excavated bones and other surviving remains. Although biomolecular methods tend to make headlines, traditional analysis – involving species, skeletal element and size identification – remains crucial to research. Nakajima and colleagues have used elegant,

easily replicable methods to establish body lengths of archaeological specimens at the Chinese Neolithic site of Jiahu dating to 6000 BC, comparing these to measurements of 301 modern carp raised in a traditional Japanese rice and fish co-culture system. Using the modern fish remains, they were able to establish that rice-fish co-culture produces a single-species concentration of smaller fish, in contrast to the variety of sizes and species found fishing wild individuals. Comparing the modern pattern to archaeological fish remains from other Chinese and Japanese sites, they were able to identify locations where some degree of management was being applied to carp.

This evidence for management raises questions of fish domestication. A domesticated animal has its breeding, food and habitat intentionally controlled by humans, often for economic benefit[9]. While it is relatively straightforward to control domestic mammal breeding, this process is more complicated in fish. Of those that could be considered domesticated (as opposed to animals bred in captivity with wild input[8] such as bluefin tunas or European eel), most have only undergone this process very recently, e.g. rainbow trout and Atlantic salmon[8]. Only two species have long been considered fully domesticated: common carp, and its close relative, the ornamental goldfish (*Carassius auratus*)[1].

Nakajima et al propose a novel three-stage process of carp aquaculture development (Figure 1): wild populations in marshy environments fished during spawning (stage 1, recognised archaeologically by a variety of species without evidence of water management), anthropogenic management of ditches and water levels to encourage natural spawning and to allow control of mass 'harvesting' of fish at similar life stages (stage 2, recognised by a single-taxon focus on similarly sized individuals, along with evidence of water management), and anthropogenic management of breeding, using spawning beds, and a more developed water management system, including use of ponds and rice paddy fields (stage 3, recognised by single-taxon focus on similarly sized individuals, alongside evidence of sophisticated water management and breeding pond use). Stage 2 is equated with Zeder's 'commensal pathway' where wild mammals are drawn into a mutually beneficial relationship with humans prior to true domestication[9]. Stage 2 is what Nakajima and colleagues identify at Jiahu c. 6000BC, where people were evidently managing ditches and ponds to control fish stocks for human use, even if animals were being replenished from wild stock.

Although not overtly stated by Nakajima et al, Stage 3 can be equated with actual domesticity, because breeding, food and habitat are all controlled by people. Previous studies have shown carp were kept in managed ponds in the Danube region during the Roman Empire – the start of carp aquaculture in Europe – and were subsequently domesticated, probably in the 12-14th century AD, driven in part by Christian fasting practices requiring regular avoidance of red meat[10]. Studies have questioned whether domestic carp were taken from Europe to China, or vice versa[1, 10]. But given the evidence for the early origins of aquaculture reported here, it seems more likely that common carp were independently domesticated twice, once in Asia, and separately in medieval Europe. If we are discussing "stage 3" domestication, we do not yet know the date of earliest Asian carp domestication. Historical and archaeological sources suggest this was by at least the first millennium BC, but because rice paddy fields date to the fifth millennium BC and Jiahu pushes aquaculture back to the sixth millennium BC, its origins may be much earlier.

Figure caption:
The three stages of common carp aquaculture in East Asia, showing progression from fishing for wild carp through to full domestication in managed ponds and rice paddies

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