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Fish commoditization and the historical origins of catching fish for profit

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Abstract

Humanity's relationship with fish dates back to prehistory, when ancestral hominins evolved the capacity to exploit aquatic resources. The impacts of early fishing on aquatic ecosystems were likely minimal, as primitive technology was used to harvest fish primarily for food. As fishing technology became more sophisticated and human populations dispersed and expanded, local economies transitioned from hunter-gatherer subsistence to barter and complex trade. This set up a positive feedback ratcheting fishing technology, mercantilization, and the commoditization of fish. A historical narrative based on archaeology and documentary evidence follows the principal changes in fisheries through evolutionary, ancient, classical and medieval eras to modern times. Some local depletions are recorded from early fishing, but from the 1950s, massive impacts of serial depletions by size, species, area and depth are driven by commoditized fishery products. North Sea herring fisheries are described in detail. Today's severely depleted wild fish populations reflect social institutions built on global markets that value fish predominantly as a consumptive commodity, risking future ecological integrity and human food security. To sustain global fisheries, decommoditization strategies that sustain human and ecosystem relationships with fish beyond their commodity value are needed.

Keywords: Commoditization; Ecological integrity; Ethics; Fish commodities; Fishing communities; History of fishing; North Sea herring; Non-market values

Introduction

From prehistory to modern times, humans have caught fish to consume and later to exchange for valuable goods and services, with local maritime economies evolving for food subsistence and then barter and complex trade. With industrialization from the late 1700s and growth in global human population and consumer demand, human ingenuity and emerging trade networks have steered waves of increasingly sophisticated fishing technology to supply fish for mass markets (Pitcher 2012). This has led to the commoditization of fish (Lam and Pitcher 2012b), with fish now being caught on an industrial scale and distributed globally for profit, exacting harmful environmental and social costs (Lam 2012, Lam and Pauly 2010) in lost resilience of local fishing communities and aquatic ecosystems. Manno (2000) describes the process of commoditization as a societal selection pressure favouring an *economy of things* (marketed goods and services) over *relationships* (embedded in communities and ecosystems). Commodities, those commercial goods and services most easily bought and sold, have the following

key attributes: they are alienable, transportable, universal, stable, and predictable, with embodied knowledge that leads to the replacement of labour by technology (Manno 2000, 2010). Current socioeconomic incentives and disincentives motivate people to preferentially harness the resources of society and nature for transformation as commodities in the market economy (Manno 2000). Today's lucrative global seafood market (Lam and Pitcher 2012b), for example, fuels the severe depletion of fishery resources, as management regimes and private fortunes are built on the market value of fish landed as a consumptive commodity, which injects growth into national economies, but at the peril of future ecological integrity and human food security (Pitcher and Lam 2010). How fisheries are managed and governed provides strong cultural and societal drivers of individual behaviours that privilege commodities over sustaining natural resources and community relationships. This is reflected in the current market economy of fisheries, with global export fishery commodities now worth over US$ 129 billion (FAO 2014).

In this paper, we trace humanity's relationship with fish through fisheries from prehistory to modern times, analyzing the historical factors that have led to the commoditization of fish, as humans have harvested fish for food, barter and complex trade, and profit. We first explore prehistoric Stone Age exploitation of aquatic resources for local subsistence by ancestral hominins. Documenting increased efficiencies and diversity of fishing gears, we show how historical improvements in fishing technology and expanded trade networks led, by the time of the Roman Empire, to surplus catches becoming tradable commodities. We suggest that continual improvements in fishing technology have enabled over-exploitation of fishery resources (Jackson et al. 2001), while human population expansion, dispersal and trade have motivated it. We argue that changes in fishing gear technology over time resulted from shortages or depletions in fish stocks and associated emergence of mercantilization, the commercial trade of fish for profit in cities, which has culminated in the modern global market economy and commoditization of fish. This, in turn, has created pressure to produce more fish, resulting in a positive feedback between technology and markets, both as drivers and products of its commoditization. To gain insight into this process, we document the diachronic interaction between the continuous tweaking of fishing technology and the emergent mercantilization of fish as a commodity in response to growing human demand for food and profit. Patchily, but steadily, this paradigm of commoditizing fish began to dominate, climaxing in the "age of industrial fishing," the modern era of unsustainable global fisheries (Lam and Pitcher 2012b).

Prehistory: early hominin subsistence use of aquatic resources

The impacts of ancestral hominins and early modern humans on aquatic ecosystems were likely minimal, as primitive technology enabled harvesting of fish mostly for local food subsistence. The archaeological record for aquatic resource use is ambiguous, given changing sea and lake levels and the differential preservation of organic remains (Erlandson 2001). However, humanity's documented prehistoric relationship with fish (Erlandson 2010) dates back to as early as 1,900,000 to 800,000 BP, when *Homo habilis* likely captured fish with little to no technology in East African lakes or streams (Stewart 1994, 2010). Pleistocene seafaring capabilities may have evolved with *Homo erectus*, as early as 800,000 BP in Indonesia (Morwood et al. 1998, Bednarik 2003). A pile of oyster

shells found in Kao Pah Nam Cave, Thailand suggests shellfish gathering, also by *Homo erectus,* 700,000 BP (Pope 1989). After 400,000 BP, archaic *Homo sapiens* increasingly used aquatic resources, but evidence of specialized fishing technology emerges only after about 150,000 BP, when anatomically modern humans, *Homo sapiens sapiens*, showed significant aquatic and maritime adaptations (Erlandson 2001), including expansion to marine diets (shellfish) and coastal habitats by 162,000 BP at Pinnacle Point Cave in South Africa (Marean et al. 2007, Marean 2010). Perforated gastropod shells were found in Israel and Algeria from the Middle Paleolithic, dating 100,000 to 135,000 BP, evidence of early symbolic use of marine resources for personal decoration (Vanhaeren et al. 2006). Barbed harpoons fashioned from the boney core of horns, found together with freshwater catfish bones, dated to 90,000 BP in two Middle Stone Age sites at Katanda, Zaire, represent the earliest known composite fishing technology (Yellen et al. 1995). By 75,000 BP (Middle Stone Age), aquatic resources were extensively exploited in human subsistence behaviour, as demonstrated by large fish bones, marine shells, seals and dolphins found with bone and stone points in Blombos Cave, South Africa (Henshilwood et al. 2001, van Niekerk 2011).

Unlike their Neanderthal relatives, *Homo neanderthalensis,* modern Stone Age humans caught fish with successively cleverer artefacts (Stringer 2002, Pitcher 2001). After harpoons (90,000 BP; Yellen et al. 1995), modern humans likely invented stone fish traps (75,000 BP; Radcliffe 1921), knotted fishing nets (35,000 BP; Adovasio et al. 1996, Pringle 1997), fish hooks made of shells (23,000 – 16,000 BP; O'Connor et al. 2011), and crafted horn, bone and stone fish hooks (18,000 BP; Sahrhage and Lundbeck 1992). The maritime technology to exploit deep sea pelagic fish like tuna may have been in existence 42,000 years ago (O'Connor et al. 2011, but see Anderson 2013). From the Gravettian Period of the Upper Paleolithic, dating from 25,000 BP, archaeological evidence of both trade and symbolic representation of fish and other marine resources (e.g., flatfish, gulls, bivalves, seals, and cetaceans) comes from the Lespugne Caves in the French Pyrenees (Bahn 1982). Although wind-drying and salting of fish (Kurlansky 2002) gave potential for trade in the Levant in the Neolithic Period (11500 – 5000 BP) and in ancient China, there is little archaeological evidence of significant declines in fish in this pre-commoditization period (evidence would be declining size or shifts in species).

Metal smelting brought bronze (5000 BP) and later, iron fish hooks (e.g., in Egypt; Brewer and Friedman 1990). As an example of early ingenious fishing technology and prolific fish resources, Mediterranean fishermen in the early thalassocracies rolled bronze-studded logs off cliffs and devised huge net traps, both techniques invented to catch abundant tuna migrating inshore (4000 BP; Oppian 169 AD). Greek and Etruscan vases record a varied and popular fish cuisine (1500 BP; Perlès and Monthel 2001). In the Iron Age, around the North Sea, periodic cultural taboos against eating fish may have existed (Dobney and Ervynck 2007).

In New World localities, such as in the Californian Coast, a diversified maritime economy, sophisticated technology, and culture with well-adapted subsistence strategies for fish, shellfish, sea mammals, and birds are suggested from stone projectile points with carved serrations from ~11,200 and 12,200 BP, likely developed for spearing fish (Erlandson et al. 2011). Erlandson and Rick (2010, Rick and Erlandson 2008) have identified local impacts of Native American fisheries on shellfish harvesting, possible effects

of sea otter harvest creating changes to inshore ecosystems through a trophic cascade, and an intriguing possibility that hunting of Steller's sea cow and the Pacific flightless cormorant significantly altered inshore ecosystems in the Northern Pacific. The local ecological knowledge, cultural identities, life ways and foraging practices of these indigenous communities have been intricately woven by their millennial relationships with fish, such as Pacific salmon, harvested from as early as 7,500 to 10,000 BP (Campbell and Butler 2010) and continuing to the present day.

Historical waves: mercantilization, fishing technology improvements, and fish trade

The paleo-archaeological evidence of fishing gear, such as the spears, hooks, and nets documented above, becomes coupled with evidence of extensive fishing activity 1000 – 500 BC, by civilizations centered on the Mediterranean Sea: the Phoenicians, Minoans, Egyptians, Assyrians, and Greeks. Here, fish is caught, traded, and marketed as part of a fishing enterprise. In the classical period of cultural history, marked by the writings of Homer in 8^{th} – 7^{th} Century BC, through the emergence of Christianity, to the decline of the Roman Empire in 5^{th} Century AD, there is clear evidence of fish trade in the Greco-Roman world. For example, an early archaeological site is a fish market with slabs and fish scales below the Church of San Nicola in Carcere in central Rome (visited by TJP), just after it was founded as an Etruscan city (400 BC) and before the Roman Republic, which ended in 44 BC.

As with many other semi-industrial enterprises, between 100 BC and about 300 AD, the well-organized Romans appear to have presided over the first intense commoditization of fish (Corcoran 1964). Sardines and anchovies were netted, fermented and dried in factories in coastal towns and made into garum – a pickled fish paste ubiquitous in Roman cooking (Corcoran 1963), used much as salt or soy sauce to sprinkle on meat, fish, vegetables or fruit (Kurlansky 2002). In Pompeii, on the coast of the Bay of Naples, garum manufacture appears to have been the principal industry (Pliny the Elder 77 CE). High-quality garum was made from small tuna in Andalusia (Roman 'Beatica') and exported in special earthenware jars (Bekker-Nielson 2002) throughout the vast Roman Empire (a 'signature' spine of tuna was placed in the bottom of each jar); see Figure 1. In Roman Britain, large quantities of garum were made in London and East Anglia probably from abundant North Sea herring (Locker 2007), where fresh herring were delivered to Roman forts (*Gariannonum*; Johnson 1976, 1980, 1983, de Caux 1881). The first reported declines in fish abundance from overfishing and of fishing fleets having to travel further to obtain fish supplies (spatial serial depletion) are found in this Roman period during the 1^{st} Century AD (Juvenal, Satire 5: 92-96, Braund 2004).

With the shift of the Roman capital to Constantinople in 324 AD and the collapse of the Western Roman Empire (476 AD), advanced economies moved east with the Eastern Roman Empire (Byzantine Empire, 476 – 1453 AD) and the Caliphates of the Early Middle Ages (Islamic Empires, 632 – 1171 AD): from this period, little is written of fisheries in the Roman texts, while Arabic texts still need to be combed for references to fish and fishing gears. Meanwhile, in northern Europe in the Middle Ages (5^{th} – 15^{th} Century), fish was a staple food of the expanding Christian monasteries and abbeys (5^{th} – 10^{th} Century), fuelled by the religious requirement to avoid meat on Fridays and during Lent: commercial documents show a flourishing herring trade on the coasts and where navigable rivers reached population centers inland. Barrett et al. (2004a) discuss how fish bones from

Figure 1 Map of trade routes in the Western Roman Empire of garum (salted, fermented fish sauce). Roman garum trade, circa 1st Century, from Baetica (Andalusia, Spain), north to Europe and Britain, and east to Italy (from Curtis 2005). Insets show a typical garum pot (or amphora) for trading found in Andalusia and a mosaic of a high-grade garum table container found in Pompeii, where garum was often refined and re-exported as a luxury item.

monastery middens reveal a growing market economy in Europe from the late 10th Century, as trade in staple commodities (such as fish for food) replaced medieval trade characterized by luxury gifts (Hodges 1982). A dramatic shift from local freshwater fish to herring and air-dried cod from Norway from the 11th Century onwards has been interpreted as a response to overfishing of local freshwater fish (Barrett et al. 2004a). Nevertheless, evidence shows dried Scandinavian cod joined herring as an important traded commodity from this period, with no reports of cod shortages (Barrett et al. 2008). Stable isotope analysis of fish bones in the southern North Sea shows that cod were initially obtained locally from the 9th to 11th Century, but during the 13th and 14th Centuries, this shifted to long distance transport, as expanding cities like London were unable to obtain fish supplies locally (Barrett et al. 2011).

Figure 2 illustrates the major events in the environmental history of the North Sea herring fishery over the last 900 years. The herring fishery (and a transition to greater harvesting of marine fish, Barrett et al. 2004a) dates back at least to the Saxon invasion of England (Alward 1932), and possibly to Roman times (see above). Worries about the consequences of heavy fishing encouraged Edward III in 1357 to pass a law regulating the expanding East Anglian herring fishery in England. Herring trade expanded in the late 1300s with the introduction in Holland of an improved curing process that allowed the salting of fresh herring in barrels at sea. During this period, in the 14th and 15th Centuries, herring fisheries in the North Sea, off southern Norway, and in the Baltic

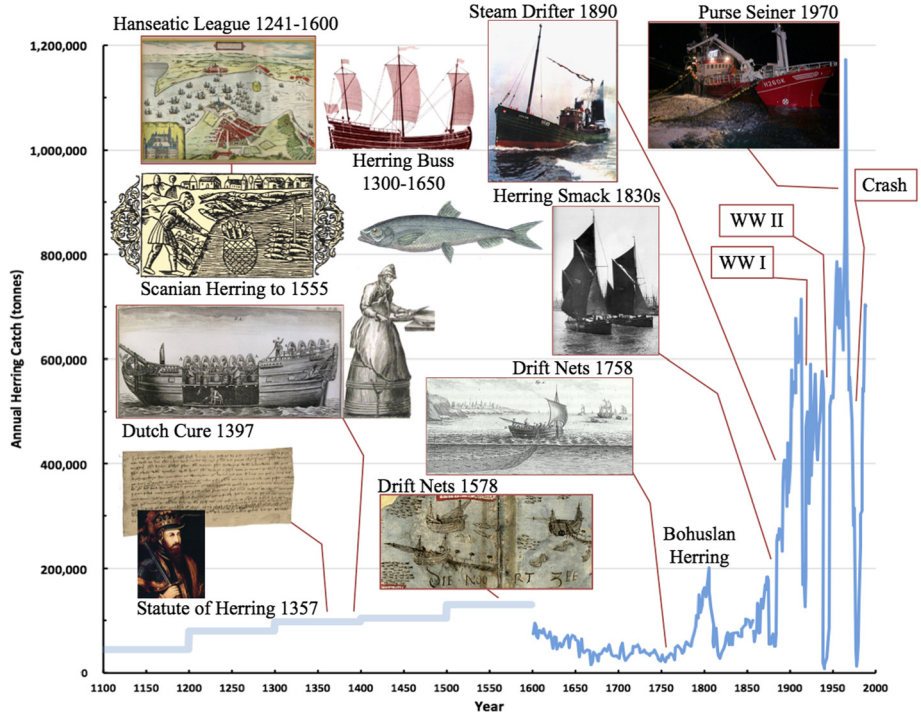

Figure 2 (See legend on next page.)

(See figure on previous page.)

Figure 2 Estimated historical catches of herring in the North Sea from 1100 AD to the present. The graph suggests that catches of 50,000 to 200,000 tonnes of herring, seen for over 800 years between 1100 and 1850 AD, were sustainable. Annual catch data were complied from estimates in Poulsen (2008; 1600-1850 AD), Cushing (1988; 1810-1950 AD), Burd (1991; 1947-1990 AD), and Mackinson (pers comm; 1880-1990 AD); where estimates overlapped, the higher was taken. Pre-1600 catches were estimated by TJP as average annual catch per century using Cushing (1988) and de Caux (1881). In all cases, the total North Sea catch is presented: this comprises a number of separate fisheries (Holland, Bremen, Scotland, East Anglia, France, Scania, Bohuslan, Altona, Limfjord, Emden). Although the spawning grounds are widely scattered, the North Sea herring stock is genetically distinct from the Irish Sea, Norwegian, Icelandic and Baltic stocks and North Sea fish are generally thought to comprise just one interbreeding population. Contemporary illustrations and labels in figure indicate some of the most significant periods and events in the environmental history of the North Sea herring fishery, described here, with catch estimates dating from the early Norman conquest, though some monastic institutions record significant herring tithes from the English herring fishery as far back as the 8th Century. Statute of Herring 1357: In 1086 in England, the Domesday Book reports many fresh and salted herring taxes, and in 1357, just after the chaos of the Black Death, Edward III enacted formal statutes to regulate the English herring fishery and markets. [Illustration from Parliamentary Rolls, courtesy of Adrian Jobson]. Dutch Cure 1397: In 1397, the Dutch Cure – salting cleaned herrings in barrels at sea – was invented (it was initially a secret process), resulting in increased demand and herring prices. [Illustration from Duhamel de Monceau 1769]. Hanseatic League 1241-1600: From the 1300s, the Hanseatic League of trading city-states (such as Lübeck and Amsterdam) founded much of their wealth on the salted herring trade [Illustration from Braun and Hogenberg 1588]. Scanian Herring to 1555: One very important stock from this time was Scanian herring in the Kattegat between Denmark and Sweden, where huge quantities of fish were caught in dip nets, beach seines and some small vessels. The Scanian herring disappeared in the late 16th Century, probably as a result of overfishing and climate change. [Illustration from Magnus 1555]. Herring Buss 1300 – 1650 and Drift Nets 1578 and 1758: From the 1300s to the late 1700s, the North Sea fishery was largely operated using drift nets set at night from 20-50 tonne "busses" [Illustrations from Adriaen Coenen's *Visboek* (1580) and du Monceau (1769)]. Bohuslan herring: North Sea herring that spawn in southern Sweden for periods of 70 to 100 years at 200 – 400 year intervals, with significant fisheries in the 1100s, 1300s, 1600s, and 1800s. The pulse shown in the late 1700s-early 1800s coincided with a decline in some of the North Sea herring fisheries, so Bohuslan herring were caught in large numbers to fill the trade gap and have not returned since. Herring Smack 1830s: In the 1800s, more advanced sail-powered fishing "smacks" also using drift nets accompanied an expansion of the fishery to well over 200,000 tonnes, probably driven by the sharp increase in northern Europe's population after the industrial revolution [Illustration from Elliott 1978]. Steam Drifter 1890: In the 1880s, the invention of steam-powered vessels setting drift nets fed a large expansion of the herring fishery to over ¾ of a million tonnes by the start of the 20th Century [Illustration from Elliott 1979]. WW I and WW II: Catches during the two 20th-Century world wars were much reduced due to the sinking of fishing vessels. Purse Seiner 1970: The huge expansion of herring catches in the 1950s and 1960s was driven largely by a burgeoning market for industrial fishmeal in the global agriculture industry. Large mechanized purse seine vessels were increasingly employed which targeted entire herring schools. [Illustration from www.afishblog.com, accessed 5 September 2014]. Crash: The herring fishery was closed as an emergency measure just before herring were almost wiped out, although some catches continued as bycatch in other fisheries. The stock recovered after 15 years and catches increased again, both for fishmeal and for human consumption. Today, the North Sea herring fishery is again overfished, showing signs of decline [Not shown].

Sea became the fountainhead of the enormous wealth of the Hanseatic League of trading cities (founded in Lübeck in 1241), which included Bergen, Amsterdam and Hamburg. In the 16th Century, the hugely important Scanian herring fishery in the strait between Sweden and Denmark (Magnus 1555) collapsed, due partly perhaps to a climate shift, but certainly to overfishing (Cushing 1988). Caught with traditional drift nets and ring seines (early purse seines), herring as a commodity continued to be vital for the economies of Holland, Scotland, eastern Britain and Scandinavia until as late as the 18th Century (de Caux 1881). Despite this commoditization, amazingly, for almost three centuries, analyzed catch rate records suggest that the Dutch North Sea herring fishery was stable and sustainable (Poulsen 2008; see also Figure 2). Extensive trade and commoditization are therefore not necessarily linked to serial destruction of a resource: during this period of relatively stable fishing technology, profitable and productive herring fisheries continued to be a part of Dutch culture. For example, Sir Walter Rayleigh

wrote in 1603 that 450,000 people in Holland owed their livelihoods to the thriving herring fishery (Poulsen 2008).

Invented by the 14th Century AD in the Late Middle Ages and possibly earlier, inshore beam trawls (see Figure 3) were used to catch dramatically more small fish and shellfish around the coasts of the North and Baltic Seas. Trawling began to compromise the productivity of inshore marine ecosystems, harming bottom-living sessile organisms (such as sea lilies, soft corals, sponges, and shellfish) that offer shelter and food to juveniles of commercially important fish. The environmental damage and waste caused by these early trawls with fine-meshed netting was so alarming to coastal communities that petitions were made to a 1376 Parliament of King Edward III of England (Ormrod 2005), and as a consequence of subsequent inquests (HMSO 1916, 1937), trawling was banned inshore in 1377. Similar concerns about local depletions and trawl bans are reported over the next three centuries in Britain, Holland and France (see Figure 3; Graham 1956), culminating in a British Act of Parliament in 1714 regulating trawling, under which illegal trawls were to be burned. However, the effectiveness of these trawl bans is questionable, as even today, the vast majority of the world's oceans are open to trawling due to the high profits to be made (Figure 4f). For example, since the late 1800s, mechanized trawling in the North Atlantic (Figure 4d) has contributed to vast losses in potential fishery benefits from intact marine ecosystems (Thurstan et al. 2010).

Following the 1300s, Europeans developed fishing technology slowly for the next 400 years, while the commoditization of fishery products, such as the herring depicted in Figure 2, developed apace with the steep growth in the merchant classes and secular meritocracy, European population, and, later, the dawn of the scientific age in the 18th Century. Thus we see that both technology and mercantilism are forces behind commoditization, as well as globalization of trade and human population growth and dispersal. For example, piracy and disputes in Iceland created a cod shortage in Europe (Roberts 2007), setting in motion the European exploitation of the New World fisheries after the huge cod populations at the Grand Banks off Newfoundland were discovered by John Cabot in the late 15th Century. This lucrative cod fishery was prosecuted by the French, British and Portuguese, and onshore processing depots developed eventually into North American settlements by the early 1700s. By the mid 18th Century,

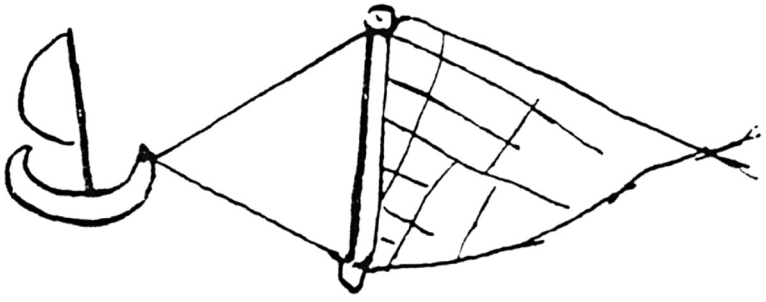

Figure 3 Sketch of a beam trawl being towed by a sailing boat from the back of an English parliamentary paper in 1635 (Graham 1959). Following successive protests of their destruction and waste, trawls were banned inshore as early as the late 1300s, but the effectiveness of these trawl bans is questionable. Today, the vast majority of the world's oceans remains open to trawling due to the high profits to be made; the largest modern (diesel-powered) trawler, the Irish-owned *Atlantic Dawn* (depicted in Figure 4f), was banned from fishing in European Union (EU) waters, but, aided by the Irish government, continued to fish elsewhere before being sold and renamed the *Annelies Ilena*.

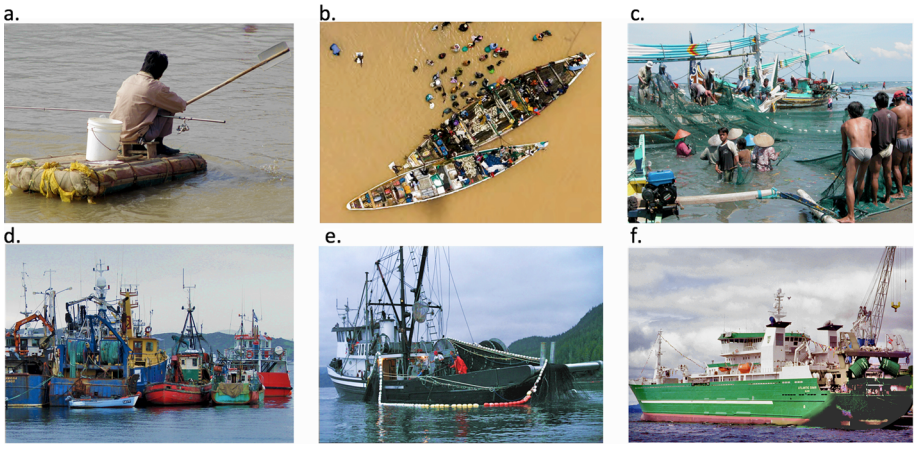

Figure 4 From fishermen to fishing boats. Increasingly, labour is being replaced by technology in modern fisheries, as small-scale, artisanal fisheries are being outcompeted in the global market economy by large-scale industrial fisheries, aided by government subsidies and favourable regulations (adapted from Lam 2012). a) Lone fisherman with rod fishing among oyster farms in Pearl River Estuary near Macau, China. Most of South China Sea has been depleted of small fish by large-scale bottom trawling (Cheung and Pitcher 2008). Photo credit: Mimi E. Lam. **b)** Fishermen on board two traditional pirogues, with fish in hold, taking cash from fish buyers, mostly women, in a small-scale coastal Senegalese fishery. The local fishery resources and communities in Senegal and other Sub-Saharan West African coastal states have been adversely impacted by EU fishing access agreements subsidizing foreign, industrial-scale vessels (Kaczynski and Fluharty 2002). Photo credit: Nicolas van Ingen. **c)** Fishermen cleaning their nets on "slereks," traditional wooden purse seiners, in the Bali Strait sardine fishery in the village of Pengambengan, Indonesia. Female gleaners in the water run fishmeal businesses, just one of many livelihoods supported by this unreported fishery (Buchary et al. 2011). Photo credit: Tony J. Pitcher. **d)** Heavily-subsidized, million-Euro, deep-sea bottom trawlers in the small village of Kinsale Harbour, West Cork, Ireland. Owner-operators are organized in a fishermen's cooperative with considerable local political power, enabling circumvention of EU regulations with impunity (Pramod and Pitcher 2006). Photo credit: Tony J. Pitcher. **e)** Chum salmon drum purse seiner with crew operating in Johnstone Strait, British Columbia, Canada. Commercial fleet corporately owned by Canfisco, the largest salmon canner in Canada, favoured by federal regulations over other, mostly owner-operated sectors (Power-Antweiler and Pitcher 2008). Photo credit: Fishing News International. **f)** *Atlantic Dawn*, previously the world's largest fishing vessel (at 144 metres in length and weighing 14,055 tons), a highly-subsidized factory trawler with nets hundreds of metres wide and full on-board filleting, freezing, and refrigeration facilities that could catch, process, and freeze 400 tons of fish every 24 hours. It has since been repainted black and renamed the *Annelies Ilena*. Photo credit: Bjørn Ottosen.

Duhamel du Monceau (1769), a French polymath of the Enlightenment, records details of well-developed Newfoundland cod fisheries employing specialized catchers, filleters, salters, dryers and packers to process cod as a major export commodity for transatlantic trade to northern Europe. He also describes extensive small-scale inshore fishing enterprises in France that utilize incredibly diverse fishing technology, driven by wind, human and horse power, similar to the small-scale fisheries seen in South East Asia (Figure 4a,c) and Africa (Figure 4b) today. The overall implication of du Monceau's work (1769) is that in the 18th Century, commercial quantities of large table fish were readily available inshore from the seas of Europe.

Expansion in the late 1700s of the salted barrel herring trade caught by drift net fisheries in Scotland seems to have led to the serial collapse of inshore herring stocks, a residential type of herring linked to a specific inshore area (almost none of this type of herring is left today), such that herring fleets had to travel further to obtain inshore catches (de Caux 1881). Here, exacerbated by the poverty conditions of crofters in Scotland, commoditization clearly led to depletions of herring. The social consequences

of this serial depletion of herring stocks, in losses of livelihoods and deaths of fishermen in severe weather, are graphically portrayed in the novel by Neil Gunn, "The Silver Darlings" (1941). Huge sail-powered fleets catching North Sea herring in drift nets (herring smacks; see Figure 2) and sail-powered trawlers catching cod and flatfish became the norm in the 1800s. Fishing fleets, owned by a new breed of entrepreneurs, would stay at sea for a month at a time, servicing the fishermen with special food, chapel and hospital boats, and fast schooners taking the fish daily to market or railheads on the coast (e.g., "Hewitts Short Blue fleet"; Alward 1932). With these improvements to technology, herring and cod catches expanded at least two-fold during this period (Poulsen 2008), and complaints of depletions from fishermen became more frequent (Thurstan et al. 2014).

To summarize, trade does not necessarily imply fish depletions, as preservation methods such as wind-drying and salting in the Neolithic (11500 – 5000 BP) and in ancient Egypt and China (dating from at least 2000 BC; Kurlansky 2002) did not lead to serious declines in fish stocks during this pre-commoditization period. Trade for profit in the Mesolithic, however, stimulated the development of a merchant class, which arose 6000 - 8000 BP, after agriculture produced a surplus of food at the dawn of cities in the Middle East, the cradle of civilization (Mesopotamia). With the Roman Civilization (509 BC – 476 AD), wealthy merchants, significant trade, and standard commodities, such as garum (Figure 1), became well established, bringing the first reported declines in fish abundance from overfishing (Juvenal Satire 5: 92-96, Braund 2004). But after the Western Roman Empire collapsed in the 5th Century AD, it was not until the Hanseatic League, founded in the 13th Century AD in the Late Middle Ages, that mercantilism, with a politically powerful merchant class and differentiation of social classes, arose in Europe. Despite extensive trade and commoditization of herring, however, this period did not generally lead to serial resource destruction: relatively stable fishing technology and profitable yet productive herring fisheries continued to be part of Dutch culture for over 300 years. Early exceptions in the Middle Ages of Europe have been documented (Hoffmann 2005), and the environmental history of Atlantic fisheries exhibits a series of local depletions and shifts in local fish communities (Bolster 2012), which can be seen as local harbingers of what was to come. But it was not until the modern age of industrial fisheries, after the 1950s, that extensive serial depletion led almost all global fishery stocks to decline to the point of being unsustainable without drastic management and policy interventions or decommoditization strategies (Lam and Pitcher 2012b).

The modern era of fisheries: mechanization, industrialization, and globalization of fish trade

Industrialization in Britain and Europe drove major commercial expansion in the Victorian Era (1837 – 1901), along with a revolution in rapid marketing of fresh fish using the new railways and cold storage. Rather than drying or salting, ice became popular for short-term preservation of fresh fish commodity to market. Ice was first reportedly used in the 1790s, transporting fresh salmon from Scotland to London (Alward 1932). Routinely cut from rivers and lakes in winter (300 ice cutters were employed in Barking, near London, in 1850), by the mid-1800s, ice was being cut from southern Norwegian lakes and exported in massive quantities, stored in ice houses

newly constructed along the shores of the southern North Sea (Alward 1932, Barli et al. 2004). After being patented by James Harrison in 1857, ice machines spread from Australia: by the 1890s, the fishing port of Grimsby, UK was making 200,000 tons of ice per year (Alward 1932).

Although from the late 1700s, side trawl design had been improved to allow fishing in deeper waters (and to avoid the inshore trawl ban; March 1953), the key invention to vastly increasing fishing power was steam-powered trawlers, which were introduced after steam tugs towing sail-powered trawlers out to sea accidentally discovered that they could catch ten times as much fish this way (William Purdy in Newcastle, UK pioneered this in 1877; Robinson 1996). Steam trawlers spread rapidly across the North Sea in the early 1880s and led to massive increases in catches and expansion of the area in which herring, flatfish and cod could be easily fished (Wimpenny 1953). In the 1890s, inventions allowed a wider spread of the net to catch more fish by the replacement of the rigid beam with hydrodynamic 'doors' (Alward 1932). These new steam-powered trawlers spread around the world by the early 1900s, alongside the improvements in cold storage. In New Zealand, Chile, Australia and South Africa, we find similar reports of newly arrived steam trawlers working their way round the coast from bay to bay, depleting fish stocks and damaging bottom-living organisms. While the boom catches were easily sold into eager fish markets, many of those diverse inshore marine ecosystems have never recovered.

Local freshwater fish have also suffered early depletions from inland commercial fisheries, as described above in the Late Middle Ages, when fishermen switched from freshwater to marine fish (Barrett et al. 2004b). In European freshwaters such as the Rhine, migratory salmon was a staple food of the poor until the 17th Century, when overfishing and the industrial revolution polluted the waters. Diadromous or migratory fish that migrate between the sea and fresh water are especially vulnerable, running a gauntlet of fishing gear as they enter rivers and lakes. Today, diadromous fish and their fisheries are in crisis; the situation is especially serious for wild salmon, which are anadromous, as they spend most of their lives in the sea and migrate to fresh water to breed. When Europeans began to colonize the Americas, migratory fisheries were seemingly limitless, but many have now collapsed due to overfishing, damming, pollution, deforestation, soil removal, and urbanization (Limburg and Waldman 2009). For example, prior to European colonization in the Pacific Northwest of North America (pre-1750s), effective traditional salmon harvesting technologies, such as fish weirs and traps, were location-specific and generated surpluses that supported, for millennia, a system of trading for local subsistence (Johnsen 2009, Trosper 2003). Complex social rules governed the capture and use of salmon and ensured that all community members had access, either to fishing locations or surplus fish. Using fishing technology based on traditional ecological knowledge acquired over many generations, cultural traditions sustained community and ecosystem relationships by "contingent proprietorship," an indigenous system of governance where rights to access, use and manage fishing sites were inalienable (Trosper 2002). Similar considerations apply to the fishing-for-salmon culture among the indigenous Saami in Norway (Lam and Borch 2011) and in the resource use of many of today's surviving indigenous peoples (Lam, in press).

With the resolution of colonial disputes in the 1800s, however, Pacific Northwest indigenous populations harvesting local resources were replaced increasingly by

Europeans focused on building fortunes, not relationships to the local resources or people, disrupting previous indigenous fishery management. Colonial governments regarded fish as commodities, whereas indigenous views were (and are) more holistic (e.g., Harris 2001, McEvoy 1986, Wadewitz 2012). This difference in perception still causes conflict in fishery management today (e.g., Heiltsuk Nation herring, Canada, Powell 2012; Haida Nation herring, Canada, Jones et al. 2010). Merchant strategies created and protected access to resources on which commercial fish businesses were built, with merchants functioning not only as fish exporters, but also as importers of essential goods, which they purchased with fish, or with the financial returns from fish purchased from settlers in a barter exchange and credit system known as "truck," such that merchants achieved effective ownership of fish accessed through purchase-by-barter (Ommer 2000). The colonial merchant economy and capitalism (1850s – early 1900s) produced surplus fish as a commodity for market, signaling a transition from traditional harvesting for local food subsistence to intense predation in modern fishing: fish was now landed as a commodity and became a source of commercial revenue. Commercial Pacific salmon was initially fished by small-scale First Nations fishermen adjacent to the resource for trade in canned salmon, financed by merchant and colonial capital, to become a major food commodity import to Britain from the late 1800s. The transition to industrial-scale capital in the 1920s financed an efficient commodity trade, with fish processed and marketed for economic viability, with freezing and capital-intensive technology, eroding local control of the fishery. Since the 1970s, a growth of corporate ownership and government subsidies for private fishing entities now threatens the sustainability of wild Pacific salmon (Knudsen et al. 2000, Lackey et al. 2006).

Historical analyses from the early 1900s to the 1950s thus show huge losses of large fish inshore in New England, France and elsewhere in North America and Europe (Roberts 2007, Fortibuoni et al. 2010). From the mid-1930s, steam-powered trawlers were progressively replaced by trawlers with diesel engines. And in the 1940s and 1950s, a number of key technological improvements greatly increased the catching power and mobility of the world's fishing fleets: A-frame stern trawlers were invented in Europe just after World War II (see Figure 4d); motorized net drums for purse seines were introduced from California in the 1950s (see Figure 4e); and the first freezer trawler (the 'Fair Try' from Britain) began operations in the late 1950s (Robinson 1996). After WW II, several technologies applied to fishing increasingly made it difficult for fish to escape predation: sonar to track aggregations of fish, radar for navigation, and Global Positioning System to mark specific locations of fish. Using large, heavily mechanized purse seiners, herring fisheries were overfished in the North Sea almost to the point of extinction by the 1960s (Burd 1991), with herring catches exceeding by a factor of ten what had proved sustainable in the successful Dutch herring fisheries of the 1700s (Poulsen 2008; see Figure 2). Here, improvements in fishing technology associated with commoditization led to overfishing and destruction of fish stocks and habitats.

From the 1950s, we have witnessed the serial depletion of inshore and northern latitude stocks (Christensen et al. 2003, Jackson et al. 2001), the advent of catches of species previously considered inedible, and the development of specialized fisheries serving burgeoning niche Asian markets. To fill this growing consumer demand, fisheries in the southern latitudes and the developing world have expanded to now comprise the majority of the world catch. Following heavy overfishing in the North Sea, North

Atlantic, Northern Pacific and Mediterranean, the South China Sea also appears to have been drastically depleted from the late 1980s (Cheung and Pitcher 2008), leading to the local extinction of many large species of fish (Liu and Sadovy 2011, Sadovy and Cheung 2003). Moreover, since the huge expansion of fishing in the 1960s, many non-traditional fish have become commoditized for the first time, including coral reef fish (often sold live), sharks for their fins used in delicacy soup, sea cucumbers, large tunas and bill fish caught with mechanized long-lines worldwide, deep sea fish and seamount fish. Fishing gear such as trawls, traps and long-lines have been progressively adapted for use in ever deeper waters (Morato et al. 2006, Norse et al. 2012), where culinarily desirable fish, such as Patagonian sea bass and orange roughy, have been mined out since the 1980s (Clark and Koslow 2007). These slow-growing, long-lived fish populations are buffered against climate fluctuations by their age classes, so the more age classes are reduced, the more fragile and less resilient these fish populations become, as it takes a long time for the fish to replace what is removed by fishing. Even remote seamounts, also characterized by long-lived, slow-growing fish, have been mined recently for their fish resources, leaving many seamounts depleted of their fish fauna and fish-eating visitors (Pitcher et al. 2010, Morato et al. 2008).

In the 1970s, hake fisheries expanded in both northern and southern hemispheres, driven by the introduction of frozen blocks as seafood commodities imported to ports with global reach in the international seafood trade, like Bremerhaven in Germany, and used to manufacture popular consumer food products like 'TV dinners'. Hake fisheries, mainly operated by increasingly large trawlers, are particularly resilient to heavy fishing because of the hake life history characteristics (Pitcher and Alheit 1995). Nevertheless, many hake fisheries have collapsed in the past 20 years (e.g., Argentine hake, UNEP 2002) because of heavy demand from the frozen block commodity market. The commodity demand even encouraged European fishing firms to transfer excess vessel capacity from European waters, financed vessel upgrades and further drove capacity growth in Argentine waters through joint ventures (UNEP 2002). New vessels were able to receive licenses from decommissioned older vessels (Kalikoski et al. 2006). Between 1989 and 1996, the processing fleet experienced a fivefold increase in fishing power (UNEP 2002) and freezer trawlers were replaced with much larger processor vessels imported from Europe, such as the *Atlantic Dawn*, now renamed the *Annelise Ilena* (see Figure 4f). These cascading issues are being tackled with a complex ITQ system, which is proving challenging to manage. While catches have increased, impacts on the ecosystem from discards of juvenile hake and bycatch of charismatic species are still serious problems in Argentina (Young 2013). At the same time, a shortfall in the frozen blocks commodity drove a diversion of fishing effort to Greenland halibut, North Pacific pollock, and South African and Chilean hake. Demand from the frozen whitefish block commodity market, where seafood products are increasingly designed to have interchangeable constituents, drives a complex global network of impacts on marine ecosystems that is prejudicial to sustainability.

The overall picture generated by this historical review of fisheries is that, with a few exceptions, fish commoditization generally followed mercantilism and a commercial market for selling fish for profit, technological improvements in fishing gear, and increasing consumer demand, which drove fish supply shortages in the market economy. Fish commoditization often, but not necessarily, caused overfishing and depletion of

the productivity and biodiversity of marine ecosystems. In response to these losses, fishing activities have sequentially moved (to new places, new depths, new species and new technologies), but today, there are almost no marine frontiers left to which to expand. With global human population just surpassing 7 billion and demand for healthy seafood commodities increasing (Lam and Pitcher 2012b), one of the few sustainable fishing options left to maintain the market supply of seafood may be to deliberately fish lower trophic levels, such as krill and other zooplankton, where 3 to 4 times the current world catch might be taken; however, their consequence for ecosystem stability and biodiversity might be very serious (Pitcher 2008; see also discussion in Pitcher and Lam 2010). Given the widespread failure of fishery management (Mora et al. 2009, Pitcher et al. 2009), such deliberate "fishing down the food web" would have to be managed more effectively than fisheries of the world have been.

Conclusion

In exploring the sad history of fish over-exploitation increasingly documented by many authors (e.g., Bolster 2012, Lotze et al. 2011, Roberts 2007, Jackson et al. 2001), we have explored the drivers and impacts of the commoditization of fish by highlighting historical interactions among human demand, technology, and mercantilization in the growing global market economy of fisheries, a trend previously traced in Southeast Asian fisheries (Bavinck 2011, Butcher 2004). New environmental ethics (Lam 2013; Lam and Pitcher 2012a, Lam and Calcari-Campbell 2012) are needed to help reverse fisheries declines from global export fish commodities worth over US$ 129 billion (FAO 2014). Policy interventions (e.g., Back-to-the-Future policy goal of restoring ecosystems; Pitcher et al. 1998, Pitcher 2005) and decommoditization strategies (e.g., valuing cultural property and instituting social subsidies; Lam and Pitcher 2012b) that value ecosystem and human relationships supported by living fish populations, in addition to fish landed for food and livelihoods, may begin to protect aquatic ecosystems and coastal communities from the adverse impacts of rising global commoditization. The balance between the numbers of fish alive and dead is critical to sustainability: most fisheries experts consider that this has been seriously compromised in many parts of the world (Pauly et al. 2002). Fish living in the sea, as opposed to fish caught and commoditized as part of a global food industry, have important non-market values that need to act as counterweights to their overexploitation as a human food resource. While seated to dine on a serving of herring, cod, or salmon, have you ever considered where the fish came from or what it was thinking and feeling before it was caught? Now, in Canada and following a trend started in London, UK, a seafood tracing system introduces consumers to the fishermen who caught their fish (Leung 2011), tightening relationships between retailers with their products, and consumers with their food. By enhancing production efficiency through supply chain traceability (see also FishPopTrace, Nielsen et al. 2012, and ThisFish™ of Ecotrust Canada), this may motivate decommoditization or simply another cycle of commoditization of a niche relationship. Identifying fish as sentient beings, research in fish cognition and behaviour (Brown et al. 2011) provides us with insights on social learning, organization, kin selection, reciprocity, cooperation, and Machiavellian intelligence, all part of the elevated suite of 'uniquely' human characteristics. A rarely considered issue in fisheries is that fishing may remove long-lived, experienced fish (Fernö et al. 2011) that act as sources of social learning in forage copying

behaviour for others (Brown and Laland 2011). Equally important and often overlooked, the emotion system in fish (Kalueff et al. 2012; Martins et al. 2012) may promote the behavioural robustness of individuals (which can exhibit distinct 'personalities'), the evolvability of gene pools, and the rate of evolutionary innovation at several trait architectural levels (Giske et al. 2014). Fish have evolved over 500 million years, much longer than humans or our hominin ancestors of 2.5 million years. Humans have exploited fishery resources for at least hundreds of millennia, yet only since the 1950s, with intense industrial fishing pressure aided by technological innovations and globalization, have humans commoditized fish (Lam and Pitcher 2012b) to the point of local extinctions and severe global depletion (Pitcher and Cheung 2013). Whether we can learn to coexist with our aquatic vertebrate elders remains to be seen, but a healthy dose of respect and awe for living fish, which have survived despite a long history of human exploitation, would augment the dietary benefits of their omega-3 oils and proteins to help ensure our own survival.

Competing interests
The authors declare that they have no competing interests.

Authors' contributions
All authors drafted, read and approved the final manuscript.

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