Marine Policy 38 (2013) 369–374

Contents lists available at SciVerse ScienceDirect

Marine Policy

journal homepage: www.elsevier.com/locate/marpol

Moving beyond the fished or farmed dichotomy

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ARTICLE INFO

Available online 28 July 2012

Keywords:
Fisheries
Aquaculture
FAO
Sustainable seafood
Typology

ABSTRACT

Seafood is widely considered to be either fished or farmed. In contrast to this perception, many types of seafood are produced by enterprises using a combination of techniques traditionally ascribed to either fisheries or aquaculture. Categorizing seafood as either fished or farmed obfuscates the growth potential and environmental impacts of global seafood production. To better capture seafood data, national and international record-keeping organizations should add a new hybrid category for seafood produced using both fisheries and aquaculture methods.

1. Introduction

Demand for seafood is currently at an unprecedented high and is predicted to increase in the future [1]. Apparent annual per capita seafood consumption has risen from 9.9 kg in the early 1960s, when the global population size was around 3 billion, to 17.1 kg in 2008, in a world of almost 7 billion people [2,3]. Seafood is a key component of global food security [4]. In 2007, fish and shellfish contributed at least 15% of the average per capita animal protein consumed by 3 billion people (many in food insecure countries). Additionally, in 2008 the seafood sector provided livelihoods for an estimated 540 million people [2]. Understanding and tracking global seafood production has high social, economic, and environmental importance.

In recent years, the growth in seafood production has generally not come from capture fisheries, whose production has effectively plateaued, but from rapid expansion of aquaculture [2]. Aquaculture provided 46% of global seafood for human consumption (i.e. excluding wild catches used for fishmeal and fish oil production) in 2008, and farmed seafood production is expected to soon exceed food fish production by capture fisheries [2,5]. Farming fish and shellfish is generally an inherently different way to produce seafood than fishing: while fisheries traditionally interact with their target population only at the time of capture, aquaculture, in its "purest" state, controls the entire lifecycle of the organism. Broadly speaking, it is accurate to conceptualize finfish and shellfish fisheries as akin to hunting and gathering and aquaculture as akin to agriculture. Yet global oceans, lakes, rivers, and ponds are populated by seafood operations that often employ methods characteristic of both production systems.

Understanding global seafood production to occupy a spectrum between notions of "pure" fisheries and "pure" aquaculture enables better accounting of the global seafood sector, including its growth potential and impacts on aquatic ecosystems. This

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http://dx.doi.org/10.1016/j.marpol.2012.06.015

paper examines the inadequacy of the current seafood production typology – fished or farmed – to meet public policy needs for understanding seafood production. To help better meet these needs, an intermediate category is proposed for describing both fisheries production that uses one or more aquaculture techniques and aquaculture production that uses one or more fisheries techniques.

2. The inadequacy of the fished or farmed dichotomy and a new production category

Fisheries often employ production methods more typically attributed to aquaculture. Likewise, some aquaculture operations rely on techniques generally attributed to fisheries [6,7]. Tables 1 and 2 highlight examples of seafood species produced with a hybrid assortment of production techniques.

Many well-known fisheries use techniques more commonly associated with aquaculture to attain greater control over their harvests (Table 1). For example, to relax natural limits on their target species' population size, fisheries for American lobster (*Homarus americanus*) modify habitats and provide additional food resources. In other examples, fisheries for Pacific salmon (*Oncorhynchus spp.*) in Alaska, New Zealand scallops (*Pecten novaezelandiae*) in New Zealand, and eastern oysters (*Crassostrea virginica*) in the Chesapeake Bay employ hatcheries to stock target populations with juveniles. The oyster and American lobster fisheries also remove sources of natural mortality via predator exclusion or culling.

Table 1
Examples of "fisheries" that use aquaculture techniques.

American lobster	
Aquaculture techniques:	
Feeding	Lobster biomass is significantly augmented through the consumption of bait by small lobsters that repeatedly enter and escape lobster traps until they reach legal catch size [20]. During a fishing season, the volume of bait inputs to the fishery often equals or exceeds the total lobster catch by a factor of two [41].
Hatchery additions	Hatcheries have been used for over 100 years in an effort to bolster lobster populations by rearing and releasing juvenile lobsters into the fishery. The impacts of hatchery additions on lobster populations are unclear [57].
Predator control	Overfishing has extirpated most lobster predators in the Gulf of Maine [21].
Chesapeake Bay Eastern oysters	
Aquaculture techniques:	
Habitat modification	To encourage settlement by juvenile oysters (called "seed") and to improve survivorship, old oyster beds are often dredged, and new beds are constructed [22].
Hatchery additions	Hatchery inputs to the Chesapeake Bay fishery are considerable. To increase survivorship of juvenile oysters, newly settled oyster juveniles are often collected on old oyster shells, which are then transferred to fishermen's leased lands for grow-out before harvest [58,59].
Predator control	Chesapeake Bay oyster harvesters use suction dredges and mops to remove predatory oyster drill snails and sea stars from oyster beds [60].
North American and New Zealand scallops	
Aquaculture techniques:	
Habitat modification	Since the late 1990s, United States and Canadian scallop fisheries management increasingly bears a resemblance to plantation-style forestry, as fishing areas are often closed for one to two years after dredging to allow populations to re-grow [24].
Hatchery additions	New Zealand scallop fisheries managers allocate rights to groups of fishermen to operate in specific areas, similar to granting a lease to an aquaculture facility. In these areas, fishermen are allowed to catch and re-seed larval scallops to bolster the populations and their catches [23].
Pacific salmon	
Aquaculture techniques:	
Hatchery additions	Hatchery-born fish accounted for about 38% of 2000–2002 salmon landings in Alaska, and there are also significant hatchery programs in British Columbia, the United States west coast states, Japan, and Russia [19,61]. Extensive recreational fisheries for Pacific salmon in the Great Lakes are also largely supported by hatchery programs in both the US and Canada [62,63].

Table 2
Examples of "aquaculture" operations that use fisheries techniques.

Bluefin tuna	
Fishery techniques:	
Fishing for stock	Bluefin tuna farms are stocked with juveniles and adults caught by purse-seine fisheries [52,53].
Fishing for feed	Bluefin tuna farms use 10–20 kg of fish as feed for every 1 kg of tuna that they produce [52].
Extensive tropical shrimp	
Fishery techniques:	
Fishing for stock	Extensive shrimp farms are generally stocked with wild-caught juveniles and adults [31].
Fishing for feed	Shrimp farms generally use fish-derived feeds [31].
Eel	
Fishery techniques:	
Fishing for stock	Eel farms in Asia and Europe are stocked with wild-caught juveniles and adults [32,64].
Fishing for feed	Eel farms often use fish-derived feeds [32,64].

Some aquaculture operations, including extensive shrimp farms (primarily giant tiger prawns, *Penaeus monodon*), bluefin tuna ranches (*Thunnus thynnus, T. orientalis,* and *T. maccoyii*), and eel farms (*Anguilla spp.*) use wild-caught animals to stock their operations (e.g., brood stock, juveniles, or adults that are caught and then cultured) (Table 2). Aquaculture of omnivorous and carnivorous fish and shellfish also uses wild inputs for feed. Fishmeal and fish oil from reduction fisheries are used in formulated feeds and whole fish are fed directly to cultured organisms [7].

Despite the frequently blurred lines between fisheries and aquaculture, they are generally managed, studied, and assessed separately. A spectrum, not a duality, more accurately describes modern seafood production; and this spectrum is not accommodated by the current dual seafood production typology (Table 3). Yet, as the fished-farmed typology is the basis for national and global data collection, the degree to which it confounds accurate understanding of the global seafood production sector is unknown.

The fished or farmed typology used to classify seafood production should be amended by adding a new intermediate production category to illuminate the gray area between fisheries and aquaculture. "Hybrid seafood production" would characterize capture fisheries that employ one or more aquaculture production techniques and aquaculture operations that rely on wild inputs.

A higher threshold for what constitutes hybrid production was considered but rejected. For instance, if a particular aquaculture operation employed two or more wild inputs, it would be reclassified as hybrid. However, this definition would exclude aquaculture systems that are "pure" but rely on fishmeal and fish oil for feed. Since the use of wild inputs for feed is an important linkage between fisheries and aquaculture production [8], the hybrid category should accommodate it. The addition of two new production categories, aquaculture-enhanced fisheries and fishery-enhanced aquaculture, was considered. However, discerning whether a particular seafood operation should be classified as one or the other could be problematic. For instance, consider a fishery slowly incorporating techniques more generally attributed to aquaculture: at what point would the manager or scientist distinguish that an aquaculture-enhanced

Table 3
Common seafood species in the global market and the fisheries and/or aquaculture techniques they employ. Dark gray denotes species generally caught by fisheries that do not use aquaculture techniques – ‘‘pure fisheries’’; white indicates species generally farmed by aquaculture operations that do not use fishery techniques – ‘‘pure aquaculture’’; and, light gray marks species that are generally produced by hybrid operations that use some combination of fishery and aquaculture techniques – ‘‘hybrid seafood production’’.

	Traditional category										
	‘‘Fisheries’’						‘‘Aquaculture’’				
	Anchoveta	Alaskan pollock	American lobster	Eastern oysters	American and NZ scallops	Alaskan salmon	Bluefin tuna	Extensive shrimp	Eel	Mussels	Silver carp
Aquaculture techniques											
Habitat modification				✓			✓	✓	✓	✓	✓
Feed augmentation			✓				✓	✓	✓	✓	✓
Hatchery additions			✓	✓	✓	✓				✓	✓
Predator exclusion or culling			✓	✓	✓	✓	✓	✓	✓	✓	✓
Fisheries techniques											
Reliance on aquatic ecosystems for feed	✓	✓	✓	✓	✓	✓	✓	✓	✓		
Reliance on aquatic ecosystems for stock	✓	✓	✓	✓	✓	✓	✓	✓	✓		

fishery had shifted to being a fishery-enhanced aquaculture operation?

3. The collection of global seafood production data

Production that incorporates both aquaculture and fishery techniques has previously been identified in the literature (e.g., capture-based aquaculture, ranching, and stock enhancement [6,9]), but an extensive review revealed no estimates of the extent to which the global seafood market is supplied by operations that use a mixture of fisheries and aquaculture methods. National and international systems for seafood production record-keeping generally do not accommodate information about hybrid production. Thus, to generate an accurate estimate of the amount of fish and shellfish produced by hybrid methods would require the concerted efforts of hundreds, if not thousands, of fisheries and aquaculture managers and scientists, each with specialist knowledge of particular seafood production systems. A tripartite typology (i.e., fished, farmed, and hybrid) built into national and international protocols for collecting seafood production data would enable national and international institutions to quantify trends in seafood production systems that use hybrid techniques and distinguish their products (in volume and value) from those produced by ‘‘pure’’ fisheries and ‘‘pure’’ aquaculture (see Table 3 for examples of ‘‘pure’’ fisheries, ‘‘pure’’ aquaculture, and hybrid production).

The central source of data about the world’s fisheries and aquaculture operations is the United Nation’s Food and Agriculture Organization (FAO). Article 1 of the FAO’s Constitution mandates that the organization collect, analyze, and distribute data about the world’s agricultural production, which for the purposes of the Constitution includes fisheries and aquaculture [10]. With fisheries catch and aquaculture production data going back to 1950, the FAO’s seafood database is an invaluable source of temporal information about the quantity, value, and geographic location of global seafood production [10,11]. However, the database reports annual seafood production via the traditional production typology and cannot accommodate inquiry about the extent and character of global seafood production that uses hybrid methods.

The biannual FAO State of World Fisheries and Aquaculture Report strives to provide ‘‘a comprehensive, objective, and global view of capture fisheries and aquaculture, including associated policy issues’’ [12], but scholars outside of the FAO have raised formidable concerns with the report and the data on which it is based. The more specific of these concerns lay outside the scope of this paper (e.g., unchecked production inflation by China and the under-reporting of small-scale fisheries catches, sharks, and bluefin tuna [11,13–15]), but a key general concern is that of data quality. To highlight and improve data quality issues, Jacquet et al. propose supplementing global wild-capture fisheries reports with metadata concerning whether a nation’s fisheries catches are known and whether they are reported accurately [16]. This proposal should be extended to cover hybrid and aquaculture production statistics as well.

Though the FAO compiles global seafood production information, the parties ultimately responsible for the data are the FAO’s member and associated nations, not the FAO itself. Annually the FAO sends out paper and electronic questionnaires to appropriate ministries and agencies of all of its member countries [10]. Submissions by member countries are compared to data of other origins and supplanted, if the other data are better. According to Garibaldi, in 2009, 24% of developed countries did not submit adequate fisheries catch data; for developing countries, that proportion was 61% [10].

Were the FAO to add another category of production to the questionnaires, would it provide a hurdle for countries that already have trouble submitting their data annually? According to Garibaldi, countries fail to report their fisheries catches because it is costly for their officials to collect reliable catch statistics, and doing so requires skilled personnel distributed across landing and production sites [10]. Jacquet et al., acknowledge this human and financial resources limitation but argue that science priorities and politics can also prevent or distort reporting [16]. In the case of countries that fail to report due to cost or human resources limitations, an additional category of production could hinder their reporting by requiring information beyond how they have traditionally tracked fisheries and aquaculture operations under their jurisdiction. However, in the case of countries that misreport their fisheries and aquaculture statistics for political reasons, another category of production would not likely influence their reporting. For the 52% of countries that submit adequate fisheries data (information regarding the FAO’s view of the adequacy of aquaculture data submissions by country is not available [10]), adding a hybrid production category would help elucidate their national understanding of domestic seafood production, as well as enhance global understanding of an important food sector.

If the FAO is to fulfill its mission to "facilitate and secure the long-term sustainable development and utilization of the world's fisheries and aquaculture" [17], it must collect more nuanced data from national agencies, including what seafood production is produced with hybrid techniques. By ignoring the spectrum-like nature of seafood production, the growth potential of seafood as an important source of animal protein in many people's diets, as well as the ecosystem impacts of the variety of seafood production methods, will continue to be obscured.

4. Better understanding of the growth potential of a critical global food source

A hybrid category of seafood production would help identify the growth potential of different types of production. Growth in fisheries production is restricted by ecosystem productivity, population size and physiology of target species, marketability of products, and regulatory, vessel design, and gear technology limitations [18]. But there is opportunity for potential growth in fisheries production when aquaculture techniques are used to reduce fisheries limitations. For example, hatcheries producing smolt and juveniles have artificially augmented wild populations of Pacific salmon, leading to increased yields [19]. Likewise, the bait additions and predator control to American lobster fisheries have likely increased the lobster population size and annual catches [20,21]. Careful engineering of eastern oyster habitat in no-fishing zones is showing the first signs of success in decades of work to rebuild the Chesapeake Bay eastern oyster population [22]. American scallop populations have rebounded in response to fisheries regulations allowing areas of the seabed to "fallow" (much like some aquaculture operations fallow ponds or net pen sites). Finally, regulations in New Zealand have recently allowed the augmentation of wild scallop populations with hatchery-reared seed [23,24]. Fisheries that incorporate aquaculture techniques may have greater growth potential than fisheries that do not incorporate these techniques. Designating these "fisheries" as "hybrid seafood production" would help identify fisheries that are potentially increasing their catches via aquaculture techniques in contrast to expanding their level of exploitation of a wild population.

Meanwhile, aquaculture is the fastest growing food sector and is expected to increase by 1.4 to 5.3% annually to maintain global per capita seafood consumption at current levels through 2020 [25]. Growth in aquaculture production is typically thought to be limited by capital, technology, regulatory constraints, marketability of products, environmental externalities, freshwater availability, and the availability of suitable space in aquatic and terrestrial environments [8,26–28]. However, growth in aquaculture operations that include fishery inputs may be constrained by issues commonly associated with fisheries. For example, bluefin tuna, extensive shrimp, and eel farms are limited by the availability of fishery-caught juveniles, adults, and feed inputs, and overfishing has occurred in many wild-capture fisheries for these species [29–33]. In these systems, production cannot increase beyond what source populations can sustain.

Development of a hybrid category of seafood production will help distinguish aquaculture systems that are dependent on shrinking wild populations from operations that are hatchery-based. Hatchery production systems likely have greater potential growth in the immediate future. Though efforts are underway to spawn and raise bluefin tuna in hatcheries to reduce reliance on wild populations, none has been commercially successful [34,35]. Efforts to reproduce eel in captivity are also underway [36]. However, in the case of farmed shrimp, successes in captive-breeding have allowed the majority of shrimp farms to move away from hybrid production techniques and stock their ponds with hatchery-raised juveniles [37].

Failure to acknowledge the mixture of techniques used in current seafood production could lead to double-counting of seafood production. For example, both Atlantic herring and American lobster are consumed directly by humans. But an estimated 70% of all Atlantic herring caught in the Gulf of Maine is used as bait in US and Canadian fisheries for American lobster [20]. If fishery production of both herring and lobster landings are summed when determining total edible seafood production, the herring biomass that is used as bait and not for direct human consumption is counted twice. Drawing attention to bait use in fisheries through a hybrid category of seafood production can help scientists, managers, and policymakers more accurately understand the net amount of seafood being produced and predict future growth trends in particular seafood production systems, as well as in global seafood supplies.

5. Better management of environmental impacts of seafood production

A hybrid category of seafood production would also help identify the environmental impacts of different types of production. Aquaculture operations can affect ecosystems through use of marine resources as feed or source stock, pollution, habitat conversion, competition and interbreeding of escaped farm-raised animals with wild populations, and amplification and transmission of diseases and parasites [8,38,39]. However, the environmental impacts of employing aquaculture techniques in fisheries are often overlooked by fisheries scientists and managers. For instance, the environmental impacts of using wild-caught animals for feed in aquaculture operations has received much study [8,33], but a similar practice in fisheries – using bait or chum to lure target animals to traps, hooks, or nets – has not.

In some fisheries in which bait is used, bait can potentially enhance yields while causing negative ecological impacts [9]. For example, management plans for American lobster fisheries do not incorporate consideration of the large amount of bait used in the fisheries, despite the fact that bait inputs (via baited pots that juvenile lobsters enter and exit at will [40]) often exceed by a substantial margin the mass of lobsters landed [41,42]. Bait additions have likely relaxed natural limits to growth of lobster populations in parts of the Gulf of Maine, altered lobster physiology, and changed competitive dynamics among species in the ecosystem [20,43]. But, because American lobster is the subject of a "fishery," feed inputs are not incorporated into the science and management that support lobster production. Considering lobster as a hybrid production class highlights the need to include the biomass of bait fed to American lobsters in scientists' population and ecosystem models. These externalities will likely continue to be invisible if data are not collected to quantify the use of aquaculture techniques in fisheries.

The ecological consequences of fisheries have also been well documented. They include: overfishing, which can impact marine food webs and lead, in extreme cases, to commercial extinction of target populations; selective removal of large individuals, which can cause demographic and evolutionary changes in target populations; unintended by catch and mortality of juveniles and/or other species; and, habitat alteration and destruction [44–50]. Both aquaculture and fisheries managers often overlook the environmental impacts of stocking aquaculture operations with wild-caught individuals. For example, bluefin tuna ranching operations, which are responsible for the majority of bluefin currently available in the market, generally do not communicate the size and age information of the tuna they capture to international tuna fisheries management agencies [51–54]. Though this information is vital for accurately measuring total fishing effort and monitoring the size of bluefin tuna populations, much of it remains proprietary to ranching operations [52,53]. Meanwhile, populations of Southern and Atlantic bluefin tuna have declined precipitously, and there has been a recent increase in the targeting of juvenile Pacific bluefin for tuna ranching [29,30,55]. Coordination between policymakers and managers of global bluefin fisheries and farming operations, with enforced reporting of bluefin caught for ranching firms, will be necessary to halt the decline of bluefin species. Categorizing bluefin farms as hybrid seafood production would help highlight the need for coordination.

6. Conclusion

Numerous seafood species are produced for the global marketplace using a spectrum of methods and cannot be cleanly ascribed as either fisheries or aquaculture. National and global data continue to be collected only along the lines of the fished or farmed typology, and the extent (in volume and value) of global hybrid seafood production remains elusive. The fished or farmed dichotomy obscures the growth potential and environmental impacts of global seafood production. We propose adding a new category of seafood production, "hybrid seafood production," to be used in national and international assessments of seafood production.

The goal of any typology is that it is "based on clear and objective criteria" and is "generalizable across regions" [56]. No typology is perfect and "definitions and classifications most often involve compromises and may not satisfy all needs," but moving beyond the traditional typology of seafood production to a tripartite categorization will engender a more accurate depiction of global seafood production [56]. Through improved data categorization, enabled by deploying an intermediate category of seafood production, it will be possible to better understand the growth potential of the global seafood sector, as well as unmask and better mitigate the environmental impacts of seafood production. Additionally, an important next step will be to quantify the proportion of global seafood production that is produced using hybrid fisheries and aquaculture techniques.

In 2002, Anderson proposed that the difference between fisheries and aquaculture was based only on the degree of control and property rights asserted by harvesters and that increasingly fisheries were becoming more and more like aquaculture via the application of a variety of property rights to their management institutions [26]. Without data to quantify how much seafood is being produced by a hybrid of techniques, Anderson's hypothesis remains untested. To achieve a clearer picture of global seafood production, a tripartite typology for seafood production statistics is needed. Without these data, transformations in the market for a critical food and livelihood source for billions of people could occur, with global analysts and policymakers being the last to know.

Acknowledgments

The authors would like to thank Elizabeth Havice, whose comments greatly improved an earlier version of this article. This work was conducted as part of the Envisioning a Sustainable Global Seafood Market and Restored Marine Ecosystems Working Group supported by the National Center for Ecological Analysis and Synthesis, a Center funded by the NSF (Grant #EF-0553768), the University of California, Santa Barbara, and the State of California. M.T. was supported by a Packard Foundation grant to the National Center for Ecological Analysis and Synthesis.

References

[1] Msangi S. Fish to 2030: meeting the steadily increasing demand for fish. AAAS Annual Meeting 2012: 17–21 February 2012. 〈http://aaas.confex.com/aaas/2011/webprogram/Paper3168.html〉 (accessed 03.05.2012).
[2] FAO. The state of world fisheries and aquaculture 2010. Rome: Food and Agricultural Organization of the United Nations; 2011 [FAO].
[3] FAO. FAOSTAT 2012. 〈http://faostat.fao.org/〉. (accessed 03.05.2012).
[4] Smith MD, Roheim CA, Crowder LB, Halpern BS, Turnipseed M, Anderson JL, et al. Sustainability and global seafood. Science 2010;327:784–786.
[5] Cressey D. Future fish. Nature 2009;458:398–400.
[6] Lovatelli A, Holthus PF. Capture-based aquaculture: global overview. FAO fisheries technical paper; 2008. p. 508.
[7] Tacon AGJ, Hasan MR, Metian M. Demand and supply of feed ingredients for farmed fish and crustaceans. FAO fisheries technical paper; 2011. p. 564.
[8] Naylor RL, Goldburg RJ, Primavera JH, Kautsky N, Beveridge MCM, Clay J, et al. Effect of aquaculture on world fish supplies. Nature 2000;405: 1017–1024.
[9] Bell JD, Bartley DM, Lorenzen K, Loneragan NR. Restocking and stock enhancement of coastal fisheries: potential, problems and progress. Fish Res 2006;80: 1–8.
[10] Garibaldi L. The FAO global capture production database: a six-decade effort to catch the trend. Mar Policy 2012;36:760–768.
[11] Pauly D, Froese R. Comments on FAO's state of fisheries and aquaculture, or 'SOFIA 2010'. Mar Policy 2012;36:746–752.
[12] FAO. The state of world fisheries and aquaculture 2008. Rome: Food and Agriculture Organization of the United Nations; 2009 [FAO].
[13] Watson R, Pauly D. Systematic distortions in world fisheries catch trends. Nature 2001;414:534–536.
[14] Zeller D, Pauly D. Reconstruction of marine fisheries catches for key countries and regions (1950–2005). Fisheries Centre research reports: Fisheries Centre—University of British Columbia; 2007.
[15] Clarke SC, McAllister MK, Milner-Gulland EJ, Kirkwood GP, Michielsens CGJ, Agnew DJ, et al. Global estimates of shark catches using trade records from commercial markets. Ecol Lett 2006;9:1115–1126.
[16] Jacquet J, Zeller D, Pauly D. Counting fish: a typology for fisheries catch data. J Integrative Environ Sci 2010;7:135–144.
[17] FAO. FAO Fisheries and Aquaculture: About us; 2011. 〈http://www.fao.org/fishery/about/en〉. (accessed 03.05.2012).
[18] Grafton RQ, Hilborn R, Squires D, Tait M, Williams MJ. Handbook of marine fisheries conservation and and management. Oxford: Oxford University Press; 2010.
[19] Knapp G, Roheim CA, Anderson JL. The great salmon run: competition between wild and farmed salmon. Washington, D.C., TRAFFIC North America; 2007.
[20] Grabowski JH, Clesceri EJ, Baukus AJ, Gaudette J, Weber M, Yund PO. Use of herring bait to farm lobsters in the Gulf of Maine. PLoS ONE 2010;5:e10188.
[21] Steneck RS, Hughes TP, Cinner JE, Adger WN, Arnold SN, Berkes F, et al. Creation of a gilded trap by the high economic value of the Maine lobster fishery. Conserv Biol 2011;25:904–912.
[22] Schulte DM, Burke RP, Lipcius RN. Unprecedented restoration of a native oyster metapopulation. Science 2009;325:1124–1128.
[23] Mincher R. New Zealand's challenger scallop enhancement company: reseeding to self-governance. In: Townsend R, Shotton R, Uchida H, editors. Case Studies in Fisheries Self-Governance. Rome: Food and Agriculture Organization of the United Nations; 2008. p. 307–322.
[24] Valderrama D, Anderson JL. Improving utilization of the Atlantic sea scallop resource: an analysis of rotational management of fishing grounds. Land Econ 2007;83:86–103.
[25] World Bank. Changing the face of the waters: the promise and challenge of sustainable aquaculture. Washington, D.C.; 2007.
[26] Anderson JL. Aquaculture and the future: Why fisheries economists should care. Mar Resour Econ 2002;17:133–151.
[27] Asche F. Farming the sea. Mar Resour Econ 2008;23:527–547.
[28] Klinger DH, Naylor R. Searching for solutions in aquaculture: charting a sustainable course. Annu Rev Environ Resour 2012:37.
[29] Taylor N, McAllister M, Lawson G, Carruthers T, Block B. Atlantic bluefin tuna: a novel multistock spatial model for assessing population biomass. PLoS ONE 2011;6:e27693.
[30] Allen R. International management of tuna fisheries: arrangements, challenges and a way forward. FAO fisheries technical paper; 2010. p 536.
[31] Giap DH, Garden P, Lebel L. Enabling sustainable shrimp aquaculture: narrowing the gaps between science and policy in Thailand. In: Lebel L, Lorek S, Daniel R, editors. Sustainable Production Consumption Systems: Knowledge, Engagement and Practice. Netherlands: Springer; 2010. p. 123–144.
[32] Nielsen T, Prouzet P. Capture-based aquaculture of wild European eel (*Anguilla anguilla*). In: Lovatelli A, Holthus PF, editors. Capture-based Aquaculture: Global Overview. Rome: Food and Agriculture Organization of the United Nations; 2008.
[33] Alder J, Campbell B, Karpouzi V, Kaschner K, Pauly D. Forage fish: from ecosystems to markets. Annu Rev Environ Resour 2008;33:153–166.
[34] Masuma S, Takebe T, Sakakura Y. A review of the broodstock management and larviculture of Pacific northern bluefin in Japan. Aquaculture 2010;315:2–8.
[35] Gluyas R. Valuable lessons breed confidence at Clean Seas. The Australian 2011.

[36] Ijiri S, Tsukamoto K, Chow S, Kurogi H, Adachi S, Tanaka H. Controlled reproduction in the Japanese eel (*Anguilla japonica*), past and present. Aquaculture Eur 2011;36:13–17.
[37] Benzie JAH. Use and exchange of genetic resources of penaeid shrimps for food and aquaculture. Rev Aquaculture 2009;1:232–250.
[38] Boyd CE, McNevin AA, Clay J, Johnson HM. Certification issues for some common aquaculture species. Rev Fish Sci 2005;13:231–279.
[39] Diana JS. Aquaculture production and biodiversity conservation. Bioscience 2009;59:27–38.
[40] Jury SH, Howell H, O'Grady III WHW DF. Lobster trap video: in situ video surveillance of the behavior of *Homarus americanus* in and around traps. Mar Freshwater Res 2001;52:1125–1132.
[41] Harnish L, Willison JHM. Efficiency of bait usage in the Nova Scotia lobster fishery: a first look. J Cleaner Prod 2009;17:345–347.
[42] Ryan RW, Holland DS, Herrera GE. Bioeconomic equilibrium in a bait-constrained fishery. Mar Resour Econ 2010;25:281–293.
[43] Myers A, Tlusty MF. A long-term assessment of the physiological effects of herring (*Clupea harengus*) as a dietary component of the American lobster (*Homarus americanus*). N Z J Mar Freshwater Res 2009;43:173–183.
[44] Crowder LB, Hazen EL, Avissar N, Bjorkland R, Latanich K, Ogburn M. The impacts of fisheries on marine ecosystems and the transition to ecosystem-based management. Annu Rev Ecol Evol Syst 2008;39:259–278.
[45] Dayton PK, Thrush SF, Agardy MT, Hofman RJ. Environmental effects of marine fishing. Aquat Conserv: Mar Freshwater Ecosyst 1995;5:205–232.
[46] Sharpe DMT, Hendry AP. Life history change in commercially exploited fish stocks: an analysis of trends across studies. Evol Appl 2009;2:260–275.
[47] Enberg K, Jorgensen C, Dunlop ES, Heino M, Dieckmann U. Implications of fisheries-induced evolution for stock rebuilding and recovery. Evol Appl 2009;2:414–934.
[48] Reynolds JD, Dulvy NK, Goodwin NB, Hutchings JA. Biology of extinction risk in marine fishes. Proc R Soc B—Biol Sci 2005;272:2337–2344.
[49] Guttormsen AG, Kristofersson D, Nævdal E. Optimal management of renewable resources with Darwinian selection induced by harvesting. J Environ Econ Manage 2008;56:167–179.
[50] NRC. Effects of trawling and dredging on seafloor habitat. National Research Council, Washington, DC: National Academy Press; 2002.
[51] FAO. Report of the third meeting of the ad hoc GFCM/ICCAT working group on sustainable bluefin tuna farming/fattening practices in the Mediterranean. 16–18 March 2005. Rome: Food and Agriculture Organization of the United Nations; 2005.
[52] Ottolenghi F. Capture-based aquaculture of bluefin. In: Lovatelli A, Holthus PF, editors. Capture-based Aquaculture: Global overview. Rome: Food and Agriculture Organization of the United Nations; 2008.
[53] Mylonas CC, De La Gandara F, Corriero A, Rios AB. Atlantic bluefin tuna (*Thunnus thynnus*) farming and fattening in the Mediterranean Sea. Rev Fish Sci 2010;18:266–280.
[54] Korman S. Note: International management of a high seas fishery: political and property-rights solutions and the Atlantic Bluefin. V J Int Law 2011;51:697–748.
[55] ISC. Report of the Pacific bluefin tuna working group workshop. Nanaimo, Canada: International Scientific Committee for Tuna and Tuna-like Species in the North Pacific Ocean; 2010.
[56] Chokkalingam U, de Jong W. Secondary forest: a working definition and typology. Int For Rev 2001;3:19–26.
[57] Nicosia F, Lavalli K. Homarid lobster hatcheries: their history and role in research, management, and aquaculture. Mar Fish Rev 1999;1:1–57.
[58] Congrove MS, Wesson JA, Allen SK Jr. A practical manual for remote setting in Virginia. VIMS marine resource report; 2009. p. 21.
[59] Bosch D, Kuminoff N, Stephenson K, Miller A, Pope J, Harris A. Evaluation of policy options for expanding oyster aquaculture in Virginia. Aquaculture Econ Manage 2010;14:145–163.
[60] Matthiessen GC. Oyster culture. Great Britain: Blackwell Science Ltd; 2001.
[61] Irvine JR, Fukuwaka M, Kaga T, Park JH, Seong KB, Kang S, et al. Pacific salmon status and abundance trends. Vancouver, Canada: North Pacific Anadromous Fish Commission; 2009 [p. 153].
[62] Kostow K. Factors that contribute to the ecological risks of salmon and steelhead hatchery programs and some mitigating strategies. Rev Fish Biol Fish 2009;19:9–31.
[63] FWS/GLFC. Great Lakes fish stocking database. U.S. Fish and Wildlife Service, Region 3 Fisheries Program, and Great Lakes Fishery Commission; 2010.
[64] Karipoglou C, Nathanailides C. Growth rate and feed conversion efficiency of intensively cultivated European eel (*Anguilla anguilla* L.). Int J Fish Aquaculture 2009;1:11–13.