Food from the Water: How the Fish Production Revolution Affects Aquatic Biodiversity and Food Security

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The production of food from marine and freshwaters is undergoing a profound revolution—from hunting to farming or from fishing to aquaculture. Fishing and aquaculture exploit and alter the biodiversity on which they are based, each in different but convergent ways. Fishing harvests a much larger range of biodiversity at ecosystem, species and genetic levels than aquaculture. Nearly 400 aquatic species are cultured and more than 5000 species captured in fisheries. Aquaculture and fishing tend to reduce genetic, species and ecosystem diversity, but along different pathways. Fishing reduces genetic and species diversity through selectively removing target individuals with desired characteristics, such as large size, and alters ecosystems. Aquaculture is currently developing across a broad front, using many different species but in inefficient ways. A deliberate program of careful species selection using a broad range of criteria for farming and markets, including food security, should be encouraged, along with research to close the lifecycles of the selected species, improved farm breeds and conservation of germplasm. Aquatic biodiversity for food production receives little policy and management attention but international research provides major support to its sustainable use and conservation.

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A myriad of aquatic biodiversity uses, benefits and threats

Aquatic biodiversity is one of humanity's most important food resources. Most of the world's oceans and all inland waters are fished, providing a protein and micro-nutrient rich food source (FRDC 2004). Fish is a vital brain food that played a role in brain evolution (Crawford *et al.* 2008).

Demand for fish and other aquatic products is rising, driven by a growing global population and escalating demand for animal protein that add to mounting pressures on the supply side: overfishing, climate change, ocean acidification and deoxygenation, water pollution from chemicals and dumping of rubbish and disruptions to nutrient, carbon and water cycles.

And on top of this is the added pressure from aquaculture, which continues to compete for space and to source some feeds and significant amounts of its seed and brood stock from wild fisheries, particularly young and juvenile fish.

The World Bank and the United Nations Food and Agriculture Organization report (World Bank 2008 and www.worldbank.org/fishnet) that the export value of world trade in fish, some US$63 billion in 2003, is more than the combined value of net exports of rice, coffee, sugar and tea.

Fishing is also a vital and valuable source of employment and income in both the developed and developing world. The OECD (Schmidt 2010) estimates that some 30 million fishers around the world make a living directly from the sea. An additional 200 million are dependent on fisheries-related activities and industries. Most of the one billion people who rely on fish as their main source of animal protein live in developing countries.

Fishing is based on harvesting diverse aquatic resources that have, over millennia, become a vital part of human life, so much so that many take eating fish for granted. And aquatic biodiversity is much more than just fish for food. It also provides raw materials for medicines and cosmetics, clarifiers for beer and wine, jewelry and ornaments, and is a tourism drawcard. Most importantly, it provides vital ecosystem services such as carbon sequestration and most of the oxygen we breathe.

For many, the popular image of fishing today focuses on the people involved, and the dangers in getting fish to the plate. The Discovery Channel, for example, is shaping this perception with its documentary series *Deadliest Catch*, now shown in 150 countries.

The program documents the Alaskan crab fishing seasons, from the perspective of crewmen on crab fishing vessels operating in the dangerous Bering Sea. Although the series highlights the dangers of the race to fish, it does not discuss sustainable harvesting levels.

Where do questions of sustainability reside in the public's imagination? How many people are aware of efforts to establish certification processes for aquatic resources sourced from sustainable fishing practices? Do consumers understand, and care, where their fish is sourced? Do they value sustainability, and how much premium would they pay for it? Have these issues been overshadowed by the drama of fishermen struggling in the extreme conditions of wild seas, hauling in cages of crab, as seen on *Deadliest Catch*?

The revolution in fish production

A more compelling drama than *Deadliest Catch* is played out each day in fisheries around the world, the daily struggle of fish workers, many of whom are women, to survive. Many of these people are poor. Indeed, most of the poor relying on fishing are labourers on other people's boats or in processing factories. Few of them have job and resource security.

Many fisheries are still engaged in a 'race to fish' approach, with catches often determined by the size of the boat, rather than sustainable management approaches. In these cases, fishers are eager to meet the rising demand for fish in the hope of an increased income and a better life.

The challenge is two-fold: ensuring that aquatic resources continue to contribute to food security and poverty reduction, without compromising aquatic biodiversity or at least minimising the trade-offs.

The successful management of fisheries and aquatic biodiversity requires an integrated approach, utilising fisheries and aquaculture policy initiatives, natural resource management approaches and aquaculture and genetic improvement. Although it is tempting to hope that aquaculture can solve the problems of overfishing and save wild fisheries, this is a false hope, no matter how tantalising and alluring. Instead we must deliver sustainable catches **and** productive aquaculture, underpinned by complementary policy environments, to meet human demand for nutritious aquatic resources.

The development and management of aquaculture is critical to sustainable wild fisheries and aquaculture is the key to future increased fish production.

Today almost half of all fish eaten are from farmed sources, not wild capture resources (Fig. 1). The change from the dominance of fish from wild capture fisheries to near parity from aquaculture has been rapid and is caused by two trends. The first is that global capture fisheries production has stalled since 1990 and is unlikely to grow further as most fish stocks are fully or over-exploited and, if well-managed, their catch levels are controlled to sustainable levels. The second trend has been the dramatic rise of aquaculture production since the early 1980s.

These trends represent a revolution in fish production, akin to, but much more rapid than, the transition from hunting to farming that started on the land 10 000 years ago and took several thousand years.

Any revolution has its consequences. Fishing and aquaculture have impacted the three levels of biological diversity—genetic diversity, species diversity and ecosystem diversity—in ways that challenge but also create opportunities for sustained fish production.

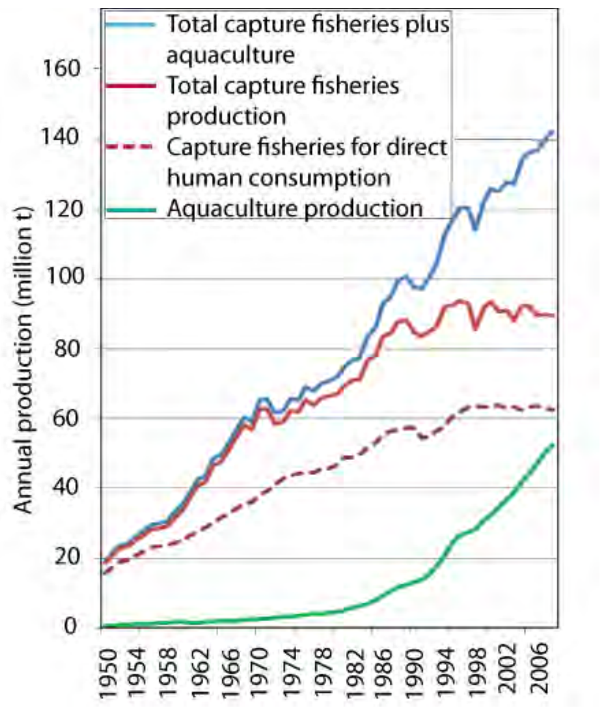

Figure 1. World fisheries and aquaculture production 1950–2008 (Source: FAO). All production statistics exclude aquatic plants and mammals.

Impacts of fishing on aquatic biodiversity

Fishing compromises genetic diversity in several ways. Fishing enterprises typically target one or several species, eventually removing some genetic stocks from the fisheries (Marteinsdóttir and Pardoe 2008) and likely reducing the long-term productivity and even survival of the species—the 'portfolio effect' (Schindler *et al.* 2010). The targeting of particular species is usually focused on larger fish, decreasing the species reproductive capacity (Field *et al.* 2008) and causing greater fluctuations in stock levels over time (Anderson *et al.* 2008).

The long-term result of fishing is to slowly shape species evolution towards lower productivity. A second longer-term result may be diminishing the diversity of discrete genetic stocks within a species (Schindler *et al.* 2010).

Fishing also changes species diversity. Within fisheries the composition of fish communities can change, with larger, valuable fish targeted, resulting in a decline in these species (Silvestre *et al.* 2003). This process of weakening the biodiversity of species can also be accelerated and exacerbated as non-target species are caught, such as marine mammals, sea turtles, sharks and other fish species taken on tuna longlines or the many non-target and undersized specimens taken in trawl nets. Such fishing impacts on species subsequently reduce the diversity of ecosystems and habitats.

Fisheries take a broad range of species. The FAO records about 2000 fish, crustacean, mollusc, echinoderm and aquatic plant species or species groups annually. But since about 10 million tonnes of **unnamed** marine fish also are landed annually, the total number of species harvested is likely to be more than 5000. Indeed, for fish species alone, not counting crustaceans, mollusks, echinoderms and aquatic plants, nearly 5000 species are used by humans (Williams 1996).

History has a lesson that we should apply to managing the apparent abundance of fisheries species today. Our ancestors developed a taste for fish and meat, with the added protein, fat and micronutrient intake helping accelerate our development, especially brain development. Many large land animals that were considered fair game were hunted to extinction by early humans. Anything that was good eating was taken. Wild food still constitutes a vital food security element for many rural people (Bharucha and Pretty 2010), but although important, this dependence is a tiny remnant compared to the period before agricultural development 10 000 years ago.

Fisheries in the modern world is driven not only by the taste for fish as basic food but even more by the strong incentives of economic gain through the market and trade. Despite the vastness of the oceans, the end result of harvesting wild fish stocks could be similar to those of many land species millennia ago—extinction of targeted stocks and even whole species.

While some would argue that such an eventually is remote, proof is mounting that humans have already had an enormous impact on aquatic species for hundreds and sometimes thousands of years (Holm *et al.* 2010). Many current fisheries are under stress. The FAO estimates that about 25% of the world's marine fish stocks are overexploited. In addition, an estimated 50% of stocks are fully exploited (FAO 2009). The depleted state of wild fish stocks is attributed to overfishing combined with increasing degradation of coastal, marine and freshwater ecosystems and habitats.

Growing coastal populations also exert increasing pressures on natural resources.

Aquaculture and aquatic biodiversity

Farming fish presents its own set of biodiversity and sustainability challenges. Aquaculture uses and affects a wide range of species, but in different ways to fishing.

In many cases cultured species are still collected from the wild at some stage in their life cycle because captive breeding has not yet been achieved (Lovatelli and Holthus 2008) or is not the object, such as in reseeding, sea ranching and restocking production systems where the progeny are released to the wild (Bell *et al.* 2008). Aquaculture is usually focused on capturing the young within a species. Culturing can involve growing out larvae through to fattening juveniles. Sometimes adults are captured for breeding.

These unimproved varieties may or may not grow well or even survive the capture and growout, wasting resources in the attempt.

If local species are not readily available for culture, then another tactic is to introduce exotic species. Depending on the situation, this may be highly successful, or highly risky because the exotic species can become established invasive species (Naylor *et al.* 2001), wrecking other forms of havoc on aquatic biodiversity.

Aquaculture is at a crossroads. It can continue to utilise available species sourced from the world's waterways and oceans, or it can narrow its focus and domesticate fewer species (Bilio 2008)—but not too few. The first road will place increased pressure on fisheries worldwide, as biodiversity is tapped in an indiscriminate and inefficient way. The second road, while longer and more challenging, is also the more sustainable, as the genetic resources of a smaller number of species are used to build reliable systems for domestication, aiding the preservation of species in the wild.

Taking this second road towards domestication will be highly dependent on international agricultural research for success. If current trends continue without the steadying hand of this research, we may find the choices of species to domesticate made for us as overfishing and inefficient
aquaculture reduce biodiversity and our choices.

Domestication, species selection and germplasm conservation in aquaculture

Aquaculture of fish species has proven to be a hit and miss affair. Some species defy all attempts at culturing, others can be grown out after being captured and some can be raised from the larval stage.

As noted above, capture fisheries production uses thousands of different aquatic species. Aquaculture has a narrower base of species but this base is still broad by comparison with food production in agriculture. In 2008, FAO reported global production statistics for 348 named aquaculture species and species groups, for which the top ten species accounted for 44% of the total volume of production. This is less concentrated than for beef, for which six cattle breeds produce 90% of world production, and food from plants, for which 12 cereals account for 80% of world production. Although terrestrial plant and animal food production runs the risk of being too narrowly based, aquaculture development is moving forward on too broad a front to be efficient and effective. Too little attention is going into the breadth of species development and its consequences.

Bilio (2008) investigated the domestication status of 202 aquaculture species and found that the likelihood of domestication was much higher in the species of greatest production. For species for which more than one million tonnes is produced annually, 75% of the species were domesticated (Fig. 2), although he did not determine whether all the production from each species was from domesticated stock. For species from which lesser quantities were produced, on average only about 20% of species were domesticated.

The goal for aquaculture, and research, must be full domestication of a carefully selected set of species. Already we have a significant body of research addressing the many stages of aquaculture for a variety of species.

This research is the foundation on which full domestication of selected species should proceed.

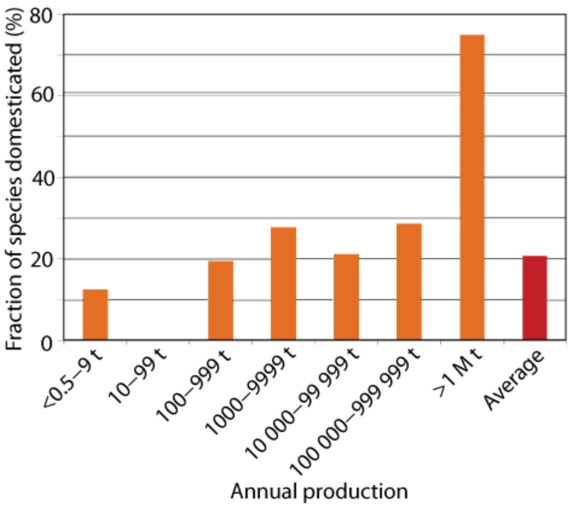

Figure 2. Fraction of animal species domesticated in relation to annual production (FAO 2006; Bilio 2008; *n* = 202 species)

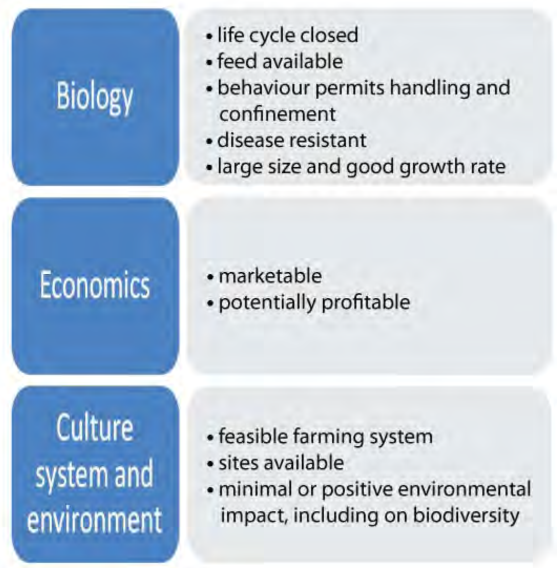

Figure 3. Species choice criteria for aquaculture

A careful selection of species with the potential for whole-of-lifecycle culturing must be based on a set of criteria emerging from these research endeavours (Fig. 3). Such research must be used to define, test, develop and prove criteria for selecting species suitable for domestication across their lifecycles (e.g. see examples in Williams and Primavera 2001).

Suitable species will be those that can be farmed throughout their lifecycles. This requires available and affordable feed. Often aquaculture is built on feeding fish with other fish, further creating pressures on aquatic biodiversity. Available feed must be sustainable and preferably from non-fish sources.

The selected species must have other traits: the ability to grow to large sizes at a suitable growth rate, and a tolerance to confinement and handling that allows farming.

Economically such species must be viable. This requires a combination of marketability and profitability.

A key component of these criteria will be species that can be efficiently cultured. From a food security perspective at least some species must be available to smallholder aquaculture producers in the developing world. Achieving this result for smallholders must also cater to issues such as space, environmental management, available finances and assets, along with training and education.

All of these factors need to be present in species selected for domestication.

As with agriculture, the improvement of farm breeds relies on biodiversity at species and genetic levels. To achieve this, conservation of fisheries resources, including germplasm, is vital. The selection of a smaller number of species must be carried out in conjunction with the preservation of genetic diversity of the selected species. To do otherwise is to limit the potential for breeding improved fish strains suitable for domestication.

The remaining link in a sustainable system for aquaculture improvement (Fig. 4) is breed improvement (Neira 2010; Rye *et al.* 2010), taking care to maintain the diversity within the improved breeds (Dixon *et al.* 2008) and addressing the many policy, economic and practical challenges of maintaining adequately diverse germplasm collections for future use (Greer and Harvey 2004). Of particular concern is the lack of policy attention, at national and international levels, to aquatic biodiversity, even in the processes of the Convention on Biological Diversity.

By focusing on fewer species, the negative effects of aquaculture on other species will be lessened, although threats will remain as aquaculture is but one factor impacting most aquatic biodiversity.

International research has already achieved much of the technology and know-how needed to develop systematic domestication, and to support sustainable management of wild fisheries.

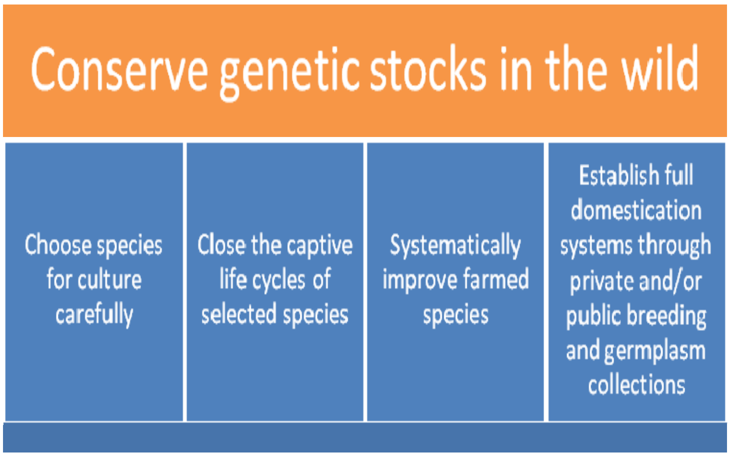

Figure 4. An integrated approach to species selection, domestication and germplasm conservation

Practical examples of taking aquatic biodiversity into account

The Australian Centre for International Agricultural Research has designed and supported fisheries research since 1984. This research has a dual focus: managing wild fisheries through innovative management approaches and better utilisation of existing harvests, in concert with improved aquaculture through the development of productive and sustainable aquatic farming systems.

As an example the WorldFish Center, in partnership with the Australian Centre for International Agricultural Research, is implementing this dual approach to sea cucumber aquaculture, focusing on viable culturing and restocking of depleted resources.

This project, active in the Philippines, Vietnam and Australia, builds on past research that developed technologies for culturing 'sandfish' (*Holothuria scabra*) in hatcheries, and for releasing this species in the wild.

This combination of technologies has the potential to assist communities, through the development of a new livelihood option, in the Philippines and Australia. Cultured sandfish are released in managed inshore habitats tended to by participating communities, which can then harvest these sandfish once they reach market size after three years.

In many areas where sea cucumber has been overfished, the culture technologies can be used to replenish selected sandfish populations. In the Philippines restocking of sandfish into marine reserves is building up a critical mass of spawning adults. The research will help to speed stock recovery, generate income and conserve wild breeding stocks.

One of the most effective means of sustaining fisheries and protecting against over-fishing is through management and monitoring. The diverse capture fisheries within Indonesian waters are among the largest and most important in the world for their value and the number of people they support (Williams 2007). These fisheries provide a food and income resource for tens of millions of people.

ACIAR is working with Indonesian partners to build capacity in monitoring catch levels and cataloguing fisheries. Research has identified deficiencies in Indonesia's fishery data/statistics that severely limit their usefulness for stock assessment. For example, catch has often not been recorded at the species level. National statistics group all the species under the single category of 'tuna'.

Complementing research on fisheries management is research to develop viable aquaculture systems. This focuses on sustainability and productivity, both vital to conserving and using biodiversity wisely.

ACIAR's support for aquaculture has helped in defining the basic taxonomy of the four Indo-Pacific mud crab species (*Scylla* spp.) (Keenan *et al.* 1998) and development of appropriate technology for hatchery and nursery production of crablets, with improved productivity in the grow-out phase (Allan and Fielder 2003; Lindner 2005).

Guidelines for the design of pens for farming crabs were developed. Building a range of pens in different types of mangrove forests, and using different techniques, was proven to be a benign, environmentally sustainable activity where guidelines are followed (Primavera *et al.* 2010).

When farmers were provided with appropriate crablet species and equipment to manage grow-out in the ponds, the growth of the crablets was rapid, with relative conformity in size and a viable survival rate compared to stocking ponds with wild seedstock.

The development of such a system for mud crabs demonstrates that aquaculture systems can be viable from both economic and environmental viewpoints.

Conclusions

Despite these good news stories, aquatic biodiversity faces huge challenges, as other fields show us. For example, let me draw a parallel. Recently the renowned fruit collection of the Vavilov Institute, housed within the Pavlovsk Experimental Station on the outskirts of St Petersburg in Russia, made headlines following pressure from developers eager to buy the station's land. The Vavilov Institute was the world's first dedicated to storing supplies of grain seed stock. During World War II a dozen scientists based at the station starved to death, rather than consume the seeds held within the collection. Yet less than a century later developers are arguing their case for buying some of the Institute's land before the Russian courts.

That one of the world's pre-eminent grain, fruit and berry seed collections can be viewed as more valuable for the land on which it is housed, than for its germplasm, says much about the challenge ahead for preserving aquatic biodiversity, much of which still needs to be conserved in-situ in water bodies threatened by dams and land reclamation for ports and cities.

The challenge has to be addressed on a number of fronts: sustainable management of wild resources, the development of domestication systems for selected fish species, and strategic and integrated policy interventions. There is no single key to unlock this challenge. It can only be approached in combination, supported by coordinated research initiatives.

Sustainable management must be integrated across fisheries and borders. This in turn requires policy action that is both strategic and sound, catering to the needs of public and private sector drivers and challenges. Food security must be a leading concern in these approaches. Yet neither policy nor fisheries management can be successful without the development of sustainable systems that domesticate farming of selected fish species. Only by closing the lifecycles for selected species, and making aquaculture production more efficient through improved breeds, can aquaculture sustainably reduce pressure on wild fisheries.

We cannot afford to give up on any facet of this challenge, otherwise there will come a day when the richness of oceanic and freshwater biodiversity may only be seen on repeats of television programs on the Discovery Channel, and not within our planet's seas and waterways.

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