A GLOBAL ANALYSIS OF HISTORICAL AND PROJECTED MARICULTURE PRODUCTION TRENDS, 1950-2030

by

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Abstract

Aquaculture is one of the fastest growing global food animal production industries and, according to the United Nations Food and Agriculture Organization (FAO), accounts for over 40 % of global seafood consumption. This proportion is anticipated to grow in the coming decades as global capture fisheries continue to stagnate and global demand for seafood continues to rise. As the significance of aquaculture grows, the marine and brackish (‘mariculture’) subsector is of particular interest for analysis because of its growing influence on the development of global aquaculture and its known negative impacts on marine biodiversity and coastal health.

Based on known global data limitations and past experience with fisheries and aquaculture statistics reported to the FAO, there is reason to independently verify the FAO’s current global database of mariculture production statistics. Moreover, its low spatial and taxonomic resolution can create uncertainties in analysis, management, and planning. We therefore re-estimated and GIS-mapped historical mariculture production from 1950 to 2004 at a higher spatial and taxonomic resolution. Despite this new compilation, some uncertainty remains in the accuracy of reported mariculture production statistics at the country level, particularly in China. As such, mariculture statistics should still be used with caution. Through analysis of mean trophic levels, this new global database confirms that we are globally ‘farming up the foodweb’.

This new database was combined with the scenarios framework of the United Nations Global Environmental Outlook (GEO-4) to reduce the uncertainty inherent in planning for, and anticipating the effects of, mariculture production’s global development trajectory by 2030. Based on the GEO-4 framework and a method using segmented linear regressions, we developed four plausible narrative storylines and model-based simulations of future mariculture, emphasizing the benefits and tradeoffs along different pathway of future development. One important result is that taking immediate action towards increasing ecological responsibility in mariculture production and development does not appear to preclude meeting currently projected food fish demand in 2030.

Preface

While the research design, data collection, compilation, analysis, and preparation of this thesis manuscript was undertaken by the primary author, a number of colleagues have contributed to this work. A version of Chapter 2, A Global Analysis of Mariculture Production: 1950-2004, will be prepared and submitted for publication, with Dr. Daniel Pauly, my supervisor, and Dr. Jackie Alder, one of my committee members, as coauthors. Both were essential in the development of the ideas behind the analysis design and Dr. Alder provided vital input during the development of the mariculture database design, data collection, and documentation stage of the research. A version of Chapter 3, Aquaculture's Global Impact in the Decades Ahead: Mariculture Development Scenarios, will also be prepared and submitted for publication, with Daniel Pauly as my coauthor. Dr. Pauly contributed to the ideas behind the analysis design.

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Chapter 1

Introduction

1.1 Problem Statement

From the beginnings of our existence, we have drawn upon any number of natural resources to create both tangible and intangible forms of wealth. This wealth is not only narrowly defined in economic terms: our natural environment also provides ecosystem services that in turn make individuals or societies better off (Daily and Ellison 2002). One such critical wealth-generating ecosystem service that helps us create a better quality of life is the provisioning of food. In our quest for an ever-improved position within our hierarchy of needs (Maslow 1943), we often believe that these environmental food services are somehow free, infinite, and invulnerable. In reality, the scope and scale of our human activities, and our tendency to rely on a short-term mindset, are damaging to our environment (Sumaila and Walters 2005). Increasingly, this mindset is threatening the productive capacity of the environments on which we depend for food.

This threat is evident in the evolution of global capture fisheries to their presently exhausted state, and in the increasing reliance placed on resource-intensive forms of aquaculture, both expected to fill our food fish supply gap and to meet the growing worldwide consumption demand for fish (Ye 1999; FAO 2009b). Projected increases in the demand for fish cannot be met by increased supply from capture fisheries alone (FAO 2004). Aquaculture has played an increasing role in providing fish[1] for human consumption for centuries. Once a minor contributor to global fisheries production, today both the freshwater and marine sectors of this practice reportedly provide nearly half of the 115 tonnes of fish we consumed worldwide in 2008 (FAO 2010c). Aquaculture, therefore, plays a pivotal role in whether the projected increases in global seafood demand will be met in the future.

The role of aquaculture has changed dramatically since the first documented production of herbivorous pond fish in China over 3000 years ago (Ling 1977). While the freshwater sector continues to provide over half of the total global aquaculture supplies of food fish, since 1970, aquaculture has witnessed a threefold increase in the production and economic value of industrial-scale and intensively-reared marine and brackish, or mariculture, species (FAO 2009b). These species fetch a high price in international markets, but the effects of their rearing practices can be detrimental to the health of coastal ecosystems

[1] 'Fish' is used to collectively refer to finfish, mollusks, crustaceans, and other farmed aquatic animals, but excludes aquatic plants (FAO 2008a).

and their people (Trujillo 2007), as well as to capture fisheries (Pullin *et al.* 1992; Wu 1995; Primavera 1997; Naylor *et al*. 1998, 2000; Goldburg 2008). As mariculture production continues to increase worldwide, these negative trends may be further exacerbated in the future and could seriously compromise the productive capacity of global fisheries, particularly if policy measures towards more widespread sustainable mariculture development are not implemented.

Globally, consumers, NGOs, policy-makers and industry alike are demanding mariculture solutions that are environmentally sustainable. This is manifest in increased consumer demand for sustainable products in developed countries, increased advocacy for, and implementation of, 'best practices' and sustainable use management policies, and changes in industry practice towards more environmentally benign production systems. Implementing these changes is no quick or easy task. Moreover, this task is intrinsically difficult for one key reason: the uncertainty arising from relying on inadequate information on global fisheries trends and issues. Global datasets for aquaculture are known to be of the poorest quality among agricultural food systems (FAO 2008b) and existing global production statistics remain at a spatial scale that is far too aggregated for effective management.

The uncertainty generated from inadequate information also weakens our ability to anticipate, based on sustainable development policies implemented today, the future effects for people, their environment, for the sector, and for global fisheries in general. Scenarios are a strategic policy analysis tool that can help explore how decisions made today impact the future. However, there is an absence of existing scenarios specific to global mariculture production. Therefore, we need improved fisheries information systems (which include aquaculture), a clearer understanding of global mariculture production trends over time, and a better grasp on their relationship to people, the environment, and global fisheries. The work presented in this thesis, which was supported by the *Sea Around Us* project, is an effort to simulate potential future consequences of policies implemented today on the long-term health and well-being of people and their environment.

1.2 Research Objectives

This research is part of ongoing broader work by the *Sea Around Us* project to improve understanding of the impact of fisheries on the world's marine ecosystems (Pauly 2007). The objectives of this thesis are threefold:

- To provide an updated, spatially and taxonomically disaggregated database of marine and brackish aquaculture production from 1950 to the present;
- To better define the role of mariculture, and thus aquaculture in general, in global fisheries production;
- To explore how sustainable mariculture policies may meet high future demand for food fish while minimally impacting on coastal ecosystems.

Also, this research may help identify critical linkages and uncertainties in processes, dynamics, and relationships that can assist in the creation of more realistic and robust policies for marine and coastal management into the future. To this end, this thesis seeks to answer the following three questions:

1. Can refining the spatial scale of global mariculture production data since 1950 decrease informational uncertainty and improve our understanding of global mariculture sector trends?
2. Will this help us better define the relationship of the mariculture subsector to aquaculture, to global fisheries, to people, and to the environment?
3. With respect to the relationships above, how will the global mariculture production sector change by 2030, if sustainable development policies are adopted and implemented worldwide today?

1.3 Thesis Outline

This thesis is organized into four chapters. Chapter one introduces the objectives of the research, outlines the structure of the manuscript, and provides the background information necessary for understanding the issues raised in the three other chapters. It introduces the history and practice of aquaculture, with mariculture as a subsector. Topical issues in aquaculture, and more specifically in mariculture, are discussed with respect to the changing social, economic, and environmental role and global context of these fish producing sectors over time. Scenarios are defined and their purpose explained. The growing popularity of their application as a tool for strategic policy analysis and foresight in environmental and resource development issues, and more specifically for fisheries, is also discussed.

Chapter two provides a spatial analysis of historic global mariculture production beginning in 1950, the first year that the Food and Agriculture Organization of the United Nations (FAO) began disseminating global fisheries and aquaculture information as part of a larger design of "quantifying the world" (Ward 2004). A global database of marine and brackish aquaculture production is presented, disaggregated to the sub-national and to the species levels for all maritime countries reporting any mariculture production from 1950 to 2004. This database was created as a means of independently validating and further refining the existing FAO Global Aquaculture Production Database (FAO 2009b). Furthermore, this new database helps toward clarifying the global role of mariculture in global fisheries production, reduces informational uncertainties, and improves the applicability of these data for a broader range of ecosystem-based coastal management policies.

This chapter also highlights the changing trends and impact of mariculture production since 1950, subsequently outlining issues chronic to the collection and interpretation of global aquaculture datasets. The collection methodology of both the FAO and what will be called the *Sea Around Us* Global Mariculture Production Database (GMPD) is discussed, and the similarities and differences between the reported production in each dataset from 1950 to 2004 is explored. The reasons for these similarities and differences are also discussed, along with their implications for a broader understanding of global fisheries issues.

Chapter three takes the conceptual framework of the United Nations Global Environmental Outlook (GEO-4) "environment for development" scenarios and applies its methodology and underlying assumptions to the exploration of four possible mariculture futures to 2030. These are based on four overarching global development themes generated in the GEO process: Markets First, Policy First, Security First, and Sustainability First, and their underlying drivers, uncertainties and critical assumptions (UNEP 2007). As a complement to the qualitative narrative storylines of possible production and sector futures, quantitative simulations of potential production trends were generated to 2030, using past trends in mariculture production extrapolated forward using a segmented linear regressions constructed using the R statistical software (RDCT 2008).

Aquaculture and the mariculture subsector are growing contributors to global food fisheries production and to human animal protein consumption worldwide (FAO 2009b). However, there is a dearth of analyses examining how broadly applied policies geared towards developing more sustainable futures could potentially affect the global mariculture production sector, global fisheries, or the future health and well-being of people and of the environment. The scenarios work in this chapter aims to help fill this gap.

The fourth and final chapter synthesizes and summarizes the findings and conclusions of the previous two chapters. The usefulness of these results for informing discussions among the general public, for environmental advocacy, and for improved mariculture management is discussed. The strengths and limitations of the analyses presented, as well as the scope for further research are also evaluated.

1.4 Background and Literature Review

1.4.1 Aquaculture defined

The most commonly accepted definition of modern aquaculture is provided by the Food and Agriculture Organization of the United Nations (FAO 2008b):

> "*The farming of aquatic organisms including fish, molluscs, crustaceans and aquatic plants*[2] *with some sort of intervention in the rearing process to enhance production, such as regular stocking, feeding, protection from predators, etc.*"

This definition of aquaculture also implies an individual or corporate ownership of these aquatic organisms throughout their rearing period (FAO 2008b). Aquaculture is not always devoted to the raising of food organisms. A well-established ornamental culture sector has existed almost as far back in history as the origins of aquaculture itself (Ling 1977), and pearl oysters are also farmed. Moreover, hatcheries and sea ranching used for wild stock enhancement and rehabilitation are also widely considered to be a form of aquaculture (FAO 2010a). Some aquaculture operations only produce aquatic organisms in nurseries up to a certain life stage for use in culture operations. The FAO however, defines aquaculture production as the output of activities producing aquatic organisms for direct human consumption (FAO 2009b), and this narrower definition will also apply here.

Aquaculture production systems

Today, aquaculture is a global practice that employs a wide variety of technologies in a wide variety of aquatic environments. Operations range in scale from community-based subsistence and artisanal farming to industrial-scale production by large multinational corporations focusing on international markets. The two principal systems of production are extensive and intensive aquaculture, which differ from each other, regardless of operational size and extent, based on the degree of system control, production efficiency, initial costs, technology use and the dependence on the surrounding natural environment for water quality and habitat use, as well as feed inputs (Bardach 1997; FAO 2008b). Variable combinations

[2] The farming of aquatic plants is not addressed within the scope of this thesis

and quantities of these key factors create hybridized semi-extensive, semi-intensive, and hyper-intensive production systems. These production systems can also be integrated, and used to produce several species at once, or combined with other agricultural activities such as rice farming, in systems known as integrated aquaculture (FAO 2008b). Which of these systems is actually used strongly determines the overall social, economic, and environmental impact of an aquaculture operation.

Extensive aquaculture

Extensive aquaculture is a production system characterized by the following features (FAO 2008b):

(i) A low degree of control (e.g. of environment, nutrition, predators, competitors, disease agents);

(ii) Low initial costs, low-level technology, and low production efficiency (yielding less than 500 kg/ha/year);

(iii) High dependence on local climate and water quality; use of natural waterbodies (e.g. lagoons, bays, embayments) and of natural (often unspecified) food organisms.

Freshwater fish, brackish species such as some shrimp, mullet (*Mugil* spp.) and marine species such as bivalve mussels (*Mytilus* spp.) are often cultured using extensive methods from a small-scale to a commercial basis (Bardach 1997). The emphasis on low costs and low inputs means that extensive systems tend to be more common when skilled labour is scarce and coastal land area is abundant, such as in the rural areas of low-income food deficit countries (FAO 1997; Kusumastanto *et al.* 1998). The characteristics of extensive culture means this practice is capable of being less intrusive overall to the surrounding environment in terms of the intensity of resource use and the instances of pollution, disease, the risks posed by invasive species, and ecosystem degradation if the operation is relatively small (Trujillo 2007). The downside of such extensive culture systems is that production is often low. Also, predation by birds and other wildlife is a common concern with less controlled culture sites (Littauer *et al.* 1997), and a heavy reliance on natural inputs such as water and land means that coastal resources may be further strained. These issues can translate into low profits, which in turn can create conditions of poor economic and social sustainability. Traditional activities (e.g., tannin production in mangrove forests or small-scale fisheries) may also be excluded by the creation of ponds and the privatization of resources, which exacerbate social and economic conflicts in coastal zones (Ardill 1982; Burbridge *et al.* 2001).

Intensive Aquaculture

Of the two forms of aquaculture, intensive culture systems have received the primary focus of attention in most regions worldwide; this is evident in a strong growth in global production tonnage in only a few decades. According to (FAO 2008b), intensive aquaculture is characterised by:

(i) A high degree of control (e.g. of environment, nutrition, predators, competitors, disease agents);

(ii) High initial costs, high-level technology, and high production efficiency (yielding a production of up to 200 tonnes/ha/year);

(iii) Tendency towards an increased independence from local climate and water quality; transition from ponds to suspended rafts, cages, raceways and tanks.

Intensive systems depend on more controlled and artificial production environments, outside inputs such as formulated feeds and medications, water exchange and aeration technologies, and high stocking densities (Ackefors *et al.* 1994). Also, growing practices place a much greater emphasis on hatchery reproduction and rearing technologies, requiring sophisticated operational management, coordination and control (Ackefors *et al*. 1994). Examples of intensively cultured species are brackish penaeid shrimp and salmon, and sometimes mussel and oyster culture. In countries such as Bangladesh, India, Indonesia, Taiwan, Thailand, and Viet Nam, semi-intensive and intensive forms of shrimp culture now dominate national production (Delgado *et al.* 2003).

The benefits of intensive culture are centered on high returns and high profits generated by more efficient production (Bardach 1997). The high degree of efficiency in production means that the quantity, size, and consistency of the grow-out product can be maximized while minimizing impacts on the surrounding environment. The jobs, and the profits generated from intensive aquaculture can be beneficial in economically depressed regions where options are limited, if the culture operation is locally owned and operated (Burbridge *et al.* 2001).

The disadvantages of intensive culture lie in what it takes to produce such high yields. The most serious problems created are a result of environmental damages and social conflict incurred by irresponsibly run and poorly sited operations. Often, negative social and environmental effects are strongest in developing countries where environmental regulations are weak or inexistent, companies are foreign, with no direct investment in local communities, fish are exported, and socio-economic needs are more pronounced (Kent 1995; Burbridge *et al.* 2001). However, aquaculture operations in developed countries often have many of these same features. Thus, for example, the rapid expansion of largely Norwegian-operated marine salmon aquaculture in the 1980s in British Columbia, a major global salmon producer, caused such strong public concern about the negative social and environmental effects of such practices that a moratorium on new farms was initiated in 1986. Despite improvements to the industry since that time and the eventual lifting of the moratorium, this negative public perception of mariculture remains along BC's coast (Hamouda *et al.* 2005).

Aquaculture production by aquatic environment

Depending on the techniques and technologies used, aquaculture operations can take place in a range of natural or completely artificial freshwater, marine or brackishwater environments. Freshwater farming, also known as inland aquaculture, is the cultivation of aquatic organisms where the end product is raised in waters with salinity that does not typically exceed 0.5 PSU[3] (FAO 2008b,2009a). The bulk of global aquaculture production (64% of 55.1 million tonnes in 2009), is produced in this environment (FAO 2010c). This excludes aquatic plants, which contributed 15.8 million tonnes and US$7.4 billion in 2008, and which are raised primarily in marine environments (FAO 2009b,2010c). While the significance of farming in the freshwater environment for the generation of food fish cannot be overstated, the scope and focus of this analysis is on production in marine and brackish environments.

Brackishwater aquaculture is conducted in water bodies with salinity levels that are intermediate between fresh and seawater. Technically, this means that end-product farming is taking place in waters with a salinity range of between 0.5 to more than 20 PSU (FAO 2010a). In practice, however, this definition is not used precisely, i.e., there is no common standard used by countries for reporting production as coming from either brackishwater or marine environments (FAO 2006). Presently, brackish environments, which include coastal lagoons, estuaries, and ponds generate about 7.7% of global aquaculture production (by weight) in 2008, with penaeid shrimps forming the bulk of global brackishwater production, followed by milkfish (*Chanos chanos*) and Nile tilapia (*Oreochromis niloticus*) (FAO 2006, 2010c).

Aquaculture in marine environments is also known as mariculture, although culture of earlier life stages may originate from other aquatic environments or from the wild (FAO 2008b). Mariculture accounts for 36% of global aquaculture production by weight and roughly 31% by value (FAO 2010c). It is practiced in coastal and offshore marine environments such as intertidal zones, fjords, and the open ocean where salinity typically exceeds 20 PSU (FAO 2010a). It may also be practiced entirely on land in containers

[3] Practical Salinity Units, more or less corresponding to part per thousand

such as seawater tanks. The most important group of farmed marine species (excluding aquatic plants) is molluscs, with 66% of global mariculture production, and 25% of all aquaculture production in 2008 (FAO 2010c), While other groups such as marine finfish (including species such as salmon, seabass, and seabream), only constituted 9% of mariculture or 3% of total global aquaculture production in 2008, these species tend to dominate global markets (FAO 2009c).

Aquaculture production by major species group

Unlike terrestrial animal husbandry, which relies on only a few dozen bird and mammal species, aquaculture relies on hundreds of different species worldwide: 245 families and 336 individual taxa were reportedly farmed in 2004 (FAO 2006). Asia and the Pacific culture the largest number of families and species worldwide, with 86 families and 204 species reported in 2004. The actual number of species cultured globally may be higher, given that many farmed groups are not defined at the species level (Nash 1988; FAO 2006). Cultured species are broadly divided into five major taxonomic groups: finfish, crustaceans, molluscs, aquatic plants, and "aquatic animals not elsewhere included (nei)". The FAO further divides finfish for statistical analyses into "freshwater", "diadromous", and "marine' species". The species within these major groupings are identified using the FAO International Standard Statistical Classification of Aquatic Animals and Plants, or ISSCAAP (FAO 2009b).

Global aquaculture production (by weight) is dominated by finfish at 64%, most of which is comprised of freshwater cyprinids such as carp (*Cyprinus* spp.) (FAO 2010c). Crustaceans, farmed in primarily marine and brackish environments and which include crabs, lobsters, and prawns, contribute 9.5% of global aquaculture production by weight but 23% in value. This comparatively high commercial value is due primarily to penaeid prawns (FAO 2010c). Molluscs such as oysters, mussels, and clams, generate 25% of global production and are farmed almost entirely in marine and brackish environments (FAO 2008a). Oysters are the second most common group in aquaculture, after cyprinids (FAO 2006), while 'Aquatic animals nei' contribute about 1% of global aquaculture production. The latter category includes species such as frogs, turtles, jellyfish, and sea urchins (FAO 2009b,2010c); these are here excluded from further analysis. Aquatic plants, while farmed in great quantities (especially in China), are also excluded from further discussion, so as to maintain the focus on the production of aquatic animal proteins.

Aquaculture by major global region

Globally, aquaculture has expanded over the centuries from a few to 168 countries and territories reporting their production to the FAO as of 2006 (FAO 2006,2008a). Asia, most notably China, has dominated global production for centuries, and the most significant sector growth over the past 50 years has also come from China. China's contribution to global aquaculture, reported as 62.3 % in 2008, is so important that this country's statistics are reported separately in globally analyses of aquaculture (FAO 2010c). Most of the Asian region produces cyprinids and oyster in great quantities; however, East Asia also produces great quantities high-value marine finfish (FAO 2006).

Latin America and the Caribbean have experienced the highest average annual growth (21% annually) since 1950 (FAO 2010c), but this is because of a low baseline; aquaculture was practically non-existent in this region prior to the 1970s. Marine and brackishwater salmon and shrimp are the primary species in this region, with the bulk of production in Chile, Ecuador, and Brazil (FAO 2006). The Near East and North Africa have experienced the second highest rate of global growth since 1950, with production concentrated on fresh and brackishwater finfish, notably mullet (*Mugil* spp.) farmed in Egypt (FAO 2006). Aquaculture growth in sub-Saharan Africa is also high, but production is still low; only 6 countries have an annual production above 5000 tonnes, with Nigeria and Madagascar as the top producing countries. Regions with a long established commercial aquaculture industry - Asia and the Pacific outside of China, Western Europe, and North America, have experienced a consistently low growth rate by comparison to other regions since 1950. The production of Atlantic salmon (*Salmo salar*) in the Western European countries of Norway and the United Kingdom, as well as in Canada has led the growth of aquaculture in these regions. Freshwater channel catfish (*Ictalurus punctatus*) culture in the USA also contributes significantly to North American production (FAO 2006).

1.4.2 A global history of aquaculture development: origins to present

The deliberate cultivation of aquatic resources for food likely began thousands of years ago when humans first learned to use natural and slightly modified water bodies such as ponds or lagoons, as well as natural seasonal water flows, to at first trap, then hold and keep, and then grow out wild fish without using outside feed inputs (Ling 1977; Rabanal 1988). As people moved from a more nomadic to a sedentary lifestyle, the farming of fish became a widely used practice for obtaining fish year-round for both consumption and trade (Rabanal 1988).

The first written historical sources of the origins of freshwater aquaculture are from 500 - 475 BC China (Rabanal 1988; Pillay and Kutty 2005). Fan Lei's "*The Classic of Fish Culture*" was the first monograph of fish culture. It contains the first written and recorded description of pond structure, of propagation, and of growth of common carp (thought to be *Cyprinus carpio)* fry, the first species deliberately reared by humans, and a species still cultured today (Ling 1977; Li and Mathias 1994). Aquaculture was limited to

China for another thousand years before the practice spread to adjacent countries. Indeed, Chinese immigrants were in many cases the key drivers behind aquaculture development and expansion into Southeast Asia and other parts of the world (Rabanal 1988; Shell 1991; Pillay and Kutty 2005), with different countries and regions adapting techniques and cultured species that suited their respective geographic areas. An example of this is the early development of pen and cage culture of catfish (*Pangasius* spp.) in Cambodia (Pillay and Kutty 2005). However, some regions, such as Polynesia, are thought to have developed aquaculture (including mariculture) independently (Kikuchi 1976; Burney 2002).

Contrary to freshwater aquaculture, the geographic origins of mariculture are less clear and may have independently originated on different continents. There is some indication that the Mediterranean region may have been the birthplace of mariculture. The Etruscans, who lived in the Latium region of Italy, are thought to have been operating the first marine farms (with no feed inputs) in the 6^{th} Century BC (Basurco and Lovatelli 2003). Both the ancient Greeks and Romans were said to have cultured oyster in the 5^{th} Century BC, and the Romans farmed seabass, seabream, and mullet using enclosures (Basurco and Lovatelli 2003; Pillay and Kutty 2005). However, clam terraces constructed by Northwest Pacific First Nations have been reported from thousands of years ago (Harper *et al.* 2002), and intertidal oyster culture may have existed in Japan for over 2000 years (Pillay and Kutty 2005).

Following the dimming of antique civilizations around Europe, aquaculture resurfaced in medieval Europe, with distinctive rearing techniques of cyprinids and pikes appearing in 11^{th} to 12^{th} Century France. By the 14^{th} Century, whole inland regions of France were producing carp on a large scale (Hoffmann 2005). By the 15^{th} Century, aquaculture had expanded considerably in operational size, although not necessarily in intensity. Extensive large-scale lagoon culture, the predecessor of 'vallicultura', had developed in the northern Adriatic (Basurco and Lovatelli 2003). The 16^{th} Century witnessed more than 100,000 ha of fish production ponds in Bohemia alone (Shell 1991).

Aquaculture emerged as a way of providing a greater, more easily accessible and more consistent year-round supply of animal protein than capture fisheries. Incremental technological advances in farming methods over time provided major production breakthroughs, increasing the success of rearing densities and stocking ratios, of general rearing and production, of fry collection and transport, and of feed, fertilizing, and disease control (Ling 1977; Rabanal 1988). Existing literature indicates that much of the focus of production in aquaculture remained primarily on more extensive methods using locally-sourced freshwater species.

Linked to global sector development over time have been the influencing social factors such as health, prestige, and religious observance. Many historic records indicate that the possessor of privately owned and reared food resource enjoyed increased status in their respective communities as a result of an enhanced supply of often limited protein resources (Kikuchi 1976; Ling 1977; Balon 1995; Hoffmann 2005). Also, it has been suggested that significant aquaculture advances in Europe were influenced by the Roman Catholic Church's prohibition of meat consumption during Lent, other festivities, and on Wednesdays and Fridays. As fish was considered a theologically acceptable animal protein, year-round demand for fish supply had already increased considerably by the 5th or 6th Century (Basurco and Lovatelli 2003; Hoffmann 2005). Also, medical views of health in Medieval Europe encouraged the consumption of fresh rather than salted flesh, which further benefited the development of aquaculture (Hoffmann 2005).

Following the scientific and industrial revolutions in the 16th to 19th centuries, the global increase in communications and information and technology exchange meant that aquaculture practices and technologies spread even more rapidly across the globe. Despite its long gestation period, the aquaculture industry we know today is relatively young. Up to the turn of the 20th Century, aquaculture provided only a small fraction of the fish consumed by humans globally (Sasson 1983). This fraction began to increase dramatically by the middle of the 20th Century.

By 1940, the world population had grown from a turn of the century estimate of 1.65 billion to 2.3 billion (US Census 2009). Following the end of World War II in 1945, the growing threat of widespread famine and malnutrition gave rise to global concern. The "Green Revolution" of cereals production, a term coined in 1968 by then USAID Director William Gaud, resulted in significant and controversial social, economic, and environmental changes to global human food production systems worldwide. Agriculture was not the only sector to experience expansion following World War II: a 'farm pond boom' swept from East to West as freshwater fish were stocked in ponds for consumption - and recreational angling (Shell 1991). Then in 1976, one of the most significant changes to global aquaculture development in the modern history of its practice came in the form of the first FAO Technical Conference on Aquaculture, held in Kyoto, Japan.

The resulting "Kyoto Declaration on Aquaculture" actively promoted aquaculture as the solution to many of the world's food and social welfare problems (FAO 1976). Shortly after the Kyoto conference, global networks were created around the world to facilitate cooperation with, and aquaculture research and development in, countries with limited economic and structural resources. In the two decades that followed the FAO Declaration, the global aquaculture industry became almost unrecognizable in scale and scope. This "Blue Revolution" (Loder 2003) of global aquaculture expansion has shifted even further from its origins as a primarily extensive, small-scale operation, to a rapidly intensifying, global, and multinational commercial enterprise.

In 2000, the Conference on Aquaculture in the Third Millennium in Bangkok was held to reassert aquaculture's critical role in alleviating poverty and augmenting livelihoods and food security[4], review the state of the industry since the 1976 Kyoto conference, and discuss the future of aquaculture (Silpachai 2001). The conference acknowledged that the poverty, livelihood, and food security goals had yet to be met and acknowledged that "some poorly planned and managed aquaculture operations have resulted in negative impacts on ecosystems and communities" (NACA and FAO 2000). The development of better management practices was promoted to improve the environmental sustainability of the practice (NACA and FAO 2000).

The broad roles aquaculture plays in human health and well-being have been consistent over the sector's history. Aquaculture has always been a provider of a year-round source of high quality animal protein. In addition to the health benefits provided by the consumption of such protein, aquaculture has served as a source of incomes, wealth and status, both as a community resource and in the broader market sense. The historic development and expansion of aquaculture has been shaped by many of the same drivers: technological innovations, market and economic demand, consumer value systems, human population growth and expansion, and the level of support from the dominant social and political institutions of the time. These roles and drivers and their shifting foci underlie both the results in the second and third thesis chapters. They will be explicitly discussed, however, in the exploration of mariculture futures in Chapter 3.

1.4.3 Topical issues in aquaculture

The following briefly discussed topical issues in aquaculture bring about much of the industry's global position in social, economic and environmental human systems. These topics will be addressed within the thesis chapters.

[4] Food security is defined by the 1996 World Food Summit as occurring "when all people at all times have access to sufficient, safe, nutritious food to maintain a healthy and active life" (Anon 1996).

Aquaculture's contribution to global fish supply

In only 50 years, aquaculture's role in global fisheries production has increased dramatically. Beginning with a production of less than 1 million tonnes in the early 1950s, global aquaculture production has grown to 52.5 million tonnes including China, and 19.8 million tonnes without, at an average growth rate of 8.3% per year since 1970, excluding aquatic plants (FAO 2010c)[5]. This rate of growth is roughly three times that of any other major animal food production sector (FAO 2006; 2010c), including that of global fisheries catches, which have been stagnant since the 1980s (Watson and Pauly 2001; FAO 2010c). Aquaculture production since 1970 has also easily outpaced an average annual human population growth of 1.6% (FAO 2010c), with per capita supply increasing at an average annual growth rate of 6.6% (FAO 2010c). However, with traditional fish-eating countries in Asia and the Pacific consuming an annual per capita average of over 25 kg of fish (FAO 2006), projections of future demand for a growing global human population imply that by 2030, a minimum of 40 million tonnes of fish will need to be added to maintain current global per capita consumption levels (FAO 2006).

Aquaculture's current sector growth trends in production seem capable of filling the food fish supply gap left by declining fisheries catches; however, there are a few factors that could prevent this goal from being achieved. A slight decline in the average annual rate of global aquaculture production growth has been observed since 2000, owing in part to a recent major downward revision in Chinese production statistics (FAO 2010c). A more moderate rate of global increase of 5.3% between 2006 and 2008 could indicate, among other factors, a maturing global aquaculture industry in some regions (FAO 2010c). Constraints to sustained or increased rates of global production include a growing emphasis on the problems associated with the intensive monoculture of high value marine and brackish carnivorous species such as salmon (Liu and Sumaila 2008) and prawn. Production of these species, while providing some positive benefits, has frequently been shown to have significant negative social and environmental impacts worldwide, as discussed below.

Another factor that could constrain the growth of aquaculture is the reliance of some of its operations on wild sourced feed and seed. While technological advances over time have meant that the dependence on wild-caught brood and seed stock is gradually diminishing (FAO 2006), some species and regions are still heavily dependent on wild resources. Brackish water-reared tiger prawn (*Penaeus monodon*), for example, still depends heavily on wild-caught breeders (FAO 2006; Primavera 2006). Culture of high

[5] It must be noted here that the FAO (FAO 2009c) remains cautious about the accuracy of aquaculture production figures supplied by China, the world's single largest producer. This mirrors an earlier situation where it was eventually uncovered that China was over-reporting its fisheries catches (Watson and Pauly 2001).

value carnivorous species is also reliant on wild-caught small pelagic fish for reduction into fishmeals and oils for feed, with little flexibility for feed alternatives (Alder *et al.* 2008). Some 46% of global fishmeals and oils were used for aquaculture feeds in 2002 (Malherbe 2005). The fisheries for small pelagic fishes needed for fishmeal and oil production currently make up 27% of total global landings of marine fish; it is likely, with global catches slowly declining, that some of these fish will be used for direct human consumption in the future (Pauly and Watson 2005; Alder *et al.* 2008). Also, given the often high feed conversion ratios of carnivorous marine and brackish species, their production may not represent a net gain to global fish production (Naylor *et al.* 2000; FAO 2006). This has brought into question the long-term sustainability of such mariculture systems (Naylor *et al.* 1998; Naylor *et al.* 2000; Tacon and Metian 2009).

Aquaculture's ecological and social impacts

Despite being promoted as a worldwide solution to poverty through food and economic security and improved livelihoods, aquaculture's success at living up to such an ambitious promise has been mixed. Any industrial-scale global food production system will have negative tradeoffs to it positive ones, and aquaculture is no different. On the positive end, aquaculture production on the whole has provided some degree of increased food fish supply, jobs, tradable commodities, and profits for many countries and regions. This is particularly evident in the rural areas of some low income food-deficit countries with a shortage of alternate available proteins; the benefits of freshwater aquaculture in Bangladesh is an often-used example (Ahmed and Lorica 2002; FAO 2006). Some claim that farmed fish can alleviate pressure on wild stocks by dampening the rise of fish prices, effectively shifting some of the fishing pressure away from higher value and highly sought-after fish like salmon and tuna, and supplementing wild fisheries (Delgado *et al.* 2003). In terms of environmental benefits, there has been some evidence to suggest that the culture of certain shellfish species can help improve the water quality of the surrounding culture environment due to the bivalves' capacity for filtration (Lindahl *et al.* 2005).

However, the environmental problems of mariculture are also quite evident. Commercial and industrial-scale farming practices are typically very intensive and require a high degree of input and infrastructure. Also, the efficiency of such systems often means that less labour is required, although the wages tend to be higher (Burbridge *et al.* 2001). Indeed, when market forces are left uncontrolled, small and economically disenfranchised coastal communities can be marginalized. This is because the culture of marine species is a primarily a profit venture for the production of luxury goods and not a contributor to food security. While low income food-deficit countries may produce large quantities of marine food fish, they are usually exported abroad to developed countries (Kent 1995; Alder and Watson 2007).

While some regulations and guidelines exist for the responsible management of fish farming operations, governance in aquaculture worldwide is generally lacking (FAO 2006). Poorly sited and managed operations can cause considerable environmental damage: disease, waste effluent, water resource overuse and quality damage, habitat conversion and ecosystem degradation, introduction of invasive species, and a removal rather than a supplementation of wild capture resources are some of the most commonly cited environmental damages that can occur (Pullin *et al.* 1993; Wu 1995; Buschmann *et al.* 1996; Naylor *et al.* 1998; Delgado *et al.* 2003).

While price-driven incentives to intensify production of mariculture species remains high regardless of the negative tradeoffs, the future productive capacity of the environment and in turn of the aquaculture sector on the whole may ultimately be constrained. Efforts to improve the sustainable development of the sector are active and underway; however there are few initiatives that include a systematic assessment of sustainability within aquaculture (Trujillo 2007). The FAO defines sustainable development as:

> *"The management and conservation of the natural resource base, and the orientation of technological and institutional change in such a manner as to ensure the attainment and continued satisfaction of human needs for present and future generations. Such sustainable development must conserve land, water, plant and animal genetic resources, is environmentally non-degrading, technically appropriate, economically viable and socially acceptable" (FAO 1988).*

It remains to be seen how issues of sustainability will be addressed in mariculture production systems once environmental and social systems become increasingly strained. While some of the ecological and social issues of mariculture are addressed in both thesis chapters, this is the topic of discussion in Chapter 3.

Global aquaculture information systems

The FAO began compiling annual national 'fish' statistics in the late 1940s, and disseminating them in 1950; these statistics combined fisheries landings with aquaculture production data, a practice continued until 1985 (FAO 2009b). While most countries now publish their most recent catch and aquaculture production statistics online, the FAO remains the primary source of global fisheries and aquaculture statistics and analyses. The data compiled, revised, analysed and disseminated by the FAO largely provides the basis of our understanding of the state of global fisheries and aquaculture and provides much of the underlying data for global decision-making and policy. However, the growing interest in and need for reliable aquaculture statistics has highlighted the fact that global information systems for aquaculture lag far behind systems for agriculture and capture fisheries (FAO 2008d). These inadequate data systems hinder a broad understanding of aquaculture's role and status throughout the regions of the world. Also, it renders efforts to responsibly monitor, assess, and manage intensifying global production and development increasingly difficult. Inadequate data also created inconsistencies in the commitments to international policy instruments such as the *Code of Conduct for Responsible Fisheries*, the *Commission for Sustainable Development*, and the *Kyoto Declaration and Plan of Action on the Sustainable Contribution of Fisheries to Food Security*. Addressing a component of this issue, Chapter 2 seeks to refine the global production dataset for mariculture, and examine the potential implications of these improvements.

1.4.4 Planning for the future: scenarios as a tool for strategic analysis

The desire to anticipate the future has long been a passion to our naturally curious species. Given the modern penchant for trusting primarily quantitative information, it is often believed that the accuracy of a forecast lay in the complexity of quantitative models. In reality, however, these models have often been found to be no more accurate than much simpler approaches (Makridakis *et al.* 1982). Inadequate information, often generated by the poor quality of underlying data and incorrect underlying model assumptions, unanticipated exogenous and endogenous system shocks, and the unpredictability of human will all compromise the accuracy of such forecasts (Ghosh 2007).

There is a growing desire to move away from unrealistic forecasting approaches providing only a numerically precise prediction of what has been identified as *the* future. This has increased interest in more qualitative and contextual methods of scenario analysis, a strategic planning tool initially developed in the 1960s for the military (Kahn and Wiener 1967), and now popular in the business world. Scenarios are a powerful and flexible tool that can be used for inspiring strategic discourse and thought, for identifying options for action and their potential broader implications, and for reducing future uncertainty (Schnaars 1987; Godet and Roubelat 1996). They focus on qualifying a given set of plausible hypotheses about a potential progression of events leading from a current situation to a future one, while focusing on causes and processes and highlighting points at which decisions must be made (Kahn and Wiener 1967). In this way, scenarios expand perspectives, and identify potential benefits and tradeoffs of future policy options. Scenarios are used as a method of exploring or anticipating a range of possible futures rather than forecasting, projecting or predicting a single one (Godet and Roubelat 1996; Pauly *et al.* 2003; Moniz 2005). They are not plans for action, but generate a set of equally likely future outcomes in preparation for which plans may be drawn (Schnaars 1987).

Scenarios are constructed using a variety of methodologies. They may contain qualitative narratives, quantitative modelling, or a combination of both. A common format for scenarios generation in the business world is the three-scenario “Good”, “Bad” and “Baseline” (Schnaars 1987). Scenarios take on many different scopes, time horizons and structures depending on the ultimate objective of the exercise. However, they are all designed with a consistent and replicable set of underlying drivers and assumptions (Raskin 2005). They may integrate across a range of contrasting states and policies, explored in either a range of background themes or within a single issue in the analysis exercise (Schnaars 1987).

Scenarios have recently gained popularity as an analysis tool in the fields of conservation planning, resource management, and sustainable development. This increase in the use of scenarios in these fields is largely a result of the development of climate change scenarios within the IPCC[6] that occurred amid growing climate change concerns in the late 1980s and early1990s (Peterson *et al.* 2003; Alder *et al.* 2007). The scenarios framework generated through this process ushered in a new era of scenarios analyses and paved the way for major global environmental and social scenarios assessments like the Millennium Ecosystem Assessment, GLOBIO[7], IAASTD[8] and GEO-4[9].

While a range of forecasts and scenarios exercise exists for the future of global fisheries (Pauly et al. 2003), the future of global aquaculture is typically based on simple extrapolations. An exception to this is IFPRI’s recent IMPACT[10] model work, which addresses aquaculture production primarily in terms of changes to the future sector based on price-based market drivers of supply and demand (Delgado *et al.* 2003). Mariculture as a subsector of aquaculture has been underrepresented thus far in both global scenarios analyses and assessments. This increases the need for analyses that identify how future development policies aimed at improving the sector’s sustainability can shape the future production of mariculture. This issue is addressed in Chapter 3, using the conceptual framework of the GEO-4 scenarios as a basis for the strategic analysis of mariculture futures.

[6] Intergovernmental Panel on Climate Change.
[7] Global Methodology for Mapping Human Impacts on the Biosphere (see www. globio.info).
[8] International Assessment of Agricultural Science Technology and Development (IAASTD 2009).
[9] United Nations’ Global Environment Outlook 4 (UNEP 2007).
[10] International Food Policy Research Institute’s International Model for Policy Analysis of Agricultural Commodities and Trade (Rosegrant *et al.* 2008).

Chapter 2

A Global Database of Historical Mariculture Production: 1950-2004

2.1 Introduction

The United Nations Food and Agriculture Organization (FAO) defines aquaculture as the farming of individually or corporately-owned aquatic organisms such as fish, molluscs, crustaceans, and aquatic plants with intervention in the rearing process so as to enhance production (FAO 2009a). It is a practice with origins dating back more than 3000 years (Ling 1977). However, aquaculture products have only recently been recognized by the United Nations Statistical Commission as distinct global commodities (FAO 2008d). As the primary warehouse for fisheries and aquaculture information worldwide since 1950 (FAO 2010b), the FAO database indicates that aquaculture's annual global production growth has increased at an average rate of 8%, surpassing any other major animal food production sector since 1970 (FAO 2010c). This rapid global increase in production from aquaculture, combined with a stagnation in global capture fisheries catches (Watson and Pauly 2001; FAO 2010c), has led to claims that aquaculture supplies "nearly half of the seafood consumed by developed markets" (Loder 2003; FAO 2009c), with the expectation that this fraction will increase further. Indeed, aquaculture is looked to as a vital complement to global capture fisheries and is envisioned to resolve food security issues worldwide (Ahmed and Lorica 2002; FAO 2003; Cunningham 2005).

However, these optimistic assessments and projections frequently overlook three key issues. The first issue relates to uncertainties in worldwide data accuracy. Our current understanding of the status of global aquaculture production relies on information provided by the FAO through reports of member countries (FAO 2005b,2009d). Many of these FAO member countries have been found to misreport capture landings (Watson and Pauly 2001; Zeller *et al.* 2007; Zeller and Pauly 2007), and the relative newness of global aquaculture statistical collections means that many of these countries also lag behind in the quality of their reported aquaculture production statistics (FAO 2005b,2008e). The second issue relates to both data accuracy and the historical distribution of global aquaculture production. Over two-thirds of aquaculture production by quantity occurs in marine, brackish, and freshwater environments in China (FAO 2010c); this means that one country is responsible for both the historical and current "blue revolution" of global aquaculture production (Loder 2003). Ongoing uncertainties over the accuracy of

Chinese aquaculture statistics, and therefore the status of global aquaculture trends, are of concern to the FAO (FAO 2009c), i.e.:

"There are continued indications that capture fisheries and aquaculture production statistics for China may be too high, as noted in previous issues of The State of World Fisheries and Aquaculture, and that this problem has existed since the early 1990s. Because of the importance of China and the uncertainty about its production statistics, as in previous issues of this report, China is generally discussed separately from the rest of the world".

The third issue relates to a shifting emphasis on production practices worldwide. Historically, aquaculture was predominantly carried out in freshwater environments with relatively low-input herbivorous and omnivorous freshwater fishes and marine bivalves (Ling 1977; Rabanal 1988). The bulk of global aquaculture production, mostly in China, still follows these trends; however, the country is increasing its use of wild-sourced fishmeals and oils to bolster its rates of production (Eleftheriou and Eleftheriou 2002;FAO 2010c). Additionally, there is a growing global focus, driven largely by demand from Western countries, on increasing the intensive production of omnivorous and carnivorous species farmed and harvested in maritime and brackish coastal environments, also known as mariculture (Goldburg and Naylor 2005; FAO 2009a). These species, such as salmon, groupers, seabasses, and prawns, are typically heavily reliant on environmental inputs such as wild-capture fishmeals and juveniles, water, land, and energy (FAO 2006; Trujillo 2007). As such, mariculture has been widely criticized for its often negative impacts on marine and coastal ecosystem health (Pullin *et al.* 1993; Naylor *et al.* 2000; Tacon and Forster 2003; Primavera 2006; Goldburg 2008; Liu and Sumaila 2010).

We consider these reasons enough to closely scrutinize the FAO Global Aquaculture Production dataset (http://www.fao.org/fishery/statistics/global-aquaculture-production/en) and then build a subset database of our own for global mariculture production. This database is compatible with the design of the other *Sea Around Us* databases, and contributes to the scientific aims of this project (Pauly 2007). This new database differs primarily from the FAO's in that both its spatial and taxonomic resolutions are much higher. In keeping with the *Sea Around Us'* goal of improving public access to global fisheries and aquaculture information, this database will be freely available online at www.seaaroundus.org.

2.2 Material and Methods

Similar to methods frequently used to reconstruct historical fisheries catches (Zeller and Pauly 2007; Zeller and Harper 2009), the construction of the *Sea Around Us* Project Global Mariculture Production Database (GMPD) used a three-pronged methodology: 1) raw production statistics for marine and brackishwater aquaculture were collected from official statistical sources, peer-reviewed and gray literature for each coastal country engaged in mariculture production, as of or up to 2004; 2) data gaps were filled using a rule-based estimation procedure that included both interpolation and extrapolation and 3) the production data were disaggregated in terms of taxonomy, i.e., groups such as 'bivalves' were split into distinct species, and geography, i.e., national production figures reported from large countries were split by the (maritime) provinces, states or territories (henceforth 'provinces') that subdivide these countries. This estimation procedure often included the use of FAO FishStat data (v.2.31) (FAO 2008a) as a starting value for disaggregation. In addition to excluding freshwater production and aquatic plants from the scope of data collection, this database, in line with the definition of mariculture given above, also excludes euryhaline freshwater cichlid and cyprinid species such as carps and tilapias (Table 2.1). The final product is a global time-series of commercial-scale marine and brackish aquaculture production presented spatially by taxa and province in whole weight tonnes (1 t = 1000 kg), for the years 1950 (coinciding with the first year of FAO data) to 2004.

Table 2.1: Marine and brackish species included in analysis, grouped according to Fishstat Plus categories. Italics denote individual species.

Included	**Partially included**	**Not Included**
Clams, cockles, arkshells	Abalones, winkles, conchs	*Periwinkles nei*
Cods, hakes, haddocks	Misc. coastal fishes	*Gobies nei*
Crabs, sea-spiders	Misc. diadromous fishes	*Three-spined stickleback*
Flounders, halibuts, soles	Salmons, Trouts, smelts	*Brook trout, Golden trout, Huchen*
Lobsters, spiny-rock lobsters		Brown Seaweeds
Marine fishes not identified		Carps, barbels and other cyprinids
Misc. demersal fishes		Freshwater Crustaceans
Misc. marine crustaceans		Freshwater Molluscs
Misc. marine molluscs		Frogs and other amphibians
Misc. pelagic fishes		Green seaweeds
Mussels		Misc. aquatic invertebrates
Oysters		Misc. aquatic plants
Pearls, mother-of-pearl, shells		Misc. freshwater fishes
Scallops, pectens		Red seaweeds
Sea-urchins and other echinoderms		River Eels
Shads		Sea-squirts and other tunicates
Shrimps, prawns		Sturgeons, paddlefishes
Squids, cuttlefishes, octopuses		Tilapias and other cichlids
Tunas, bonitos, billfishes		Turtles

***Source**: FAO FISHSTAT PLUS (2008a), Aquaculture production 1950 - 2006 (downloadable)*

2.2.1 Sources of data

To determine whether a given country or territory was engaged in commercial mariculture production in the 2004 or earlier, we searched a given country's agriculture, fisheries, statistics, or other ministerial departments or divisions for general information on mariculture activities. If it was not possible to determine whether commercial mariculture was taking place using this method, a broader search of the scientific and technical literature was conducted. The FAO National Aquaculture Sector Overview

(NASO) datasheets (www.fao.org/fishery/naso/search/en) were often a useful departure point for data searches. 'Commercial mariculture production' in this instance refers to the profit-oriented output of marine and brackish farming activities designated for final harvest for consumption (FAO 2009b); as such subsistence mariculture production and raising fingerlings for wild stock enhancement are excluded from reporting and from this analysis. We determined that 112 of the 187 maritime countries and territories in the *Sea Around Us* database (*Sea Around Us* 2009) were actively engaged in commercial mariculture production as of 2004 and that only a few countries (e.g., Estonia, Gambia) had engaged in, then abandoned this activity since 1950 (Table 2.2).

Table 2.2: Regional grouping of 112 coastal countries and territories actively engaged in commercial mariculture as of or up to 2004. The total number of coastal countries in a given region is compared in parentheses.

Region	Countries or territories (having a unique UN/ISO country code)
Africa (17 of 41 countries)	Algeria, Egypt, *Eritrea*, Kenya, Libyan Arab Jamahiriya, Madagascar, Mauritius, Mayotte (FR), Morocco, Mozambique, Namibia, Nigeria, Réunion (FR), Senegal, Seychelles, South Africa, Tunisia **Mediterranean Africa:** Algeria, Egypt, Libyan Arab Jamahiriya, Morocco, Tunisia
Asia (31 of 38 countries)	Bahrain, Bangladesh, Brunei, Cambodia, China, Hong Kong SAR (CN), India, Indonesia, Iran, Israel, Japan, Korea Dem. Rep., Korea Rep., Kuwait, *Lebanon*, Malaysia, Myanmar, Oman, Pakistan, Philippines, Qatar, Russian Federation, Saudi Arabia, Singapore*, Sri Lanka, Taiwan, Timor-Leste, Thailand, United Arab Emirates, Viet Nam, Yemen **Mediterranean Asia:** Israel, *Lebanon*
Europe (26 of 35 countries)	Albania, Bosnia and Herzegovina, Bulgaria, Channel Is (UK), Croatia, Cyprus, Denmark, Faeroe Is (DK), Finland, France, Germany, Greece, Iceland, Ireland, Italy, Malta, Montenegro, Netherlands, Norway, Portugal, Slovenia, Spain, Sweden, Turkey, Ukraine, United Kingdom **Mediterranean Europe:** Albania, Bosnia and Herzegovina, Croatia, Cyprus, France, Greece, Italy, Malta, Montenegro, Slovenia, Spain, Turkey **Northern Europe:** Channel Is (UK), Denmark, Faeroe Is (DK), Finland, France, Germany, Iceland, Ireland, Netherlands, Norway, Sweden, United Kingdom
Americas (28 of 48 countries)	Argentina, Bahamas, Belize, Brazil, Canada, Chile, Colombia, Costa Rica, Cuba, Dominican Republic, Ecuador, El Salvador, Falkland Is (UK), Guatemala, Guyana, Honduras, Jamaica, Martinique (FR), Mexico, Netherlands Antilles (NL), Nicaragua, Panama, Peru, Puerto Rico (USA), Suriname, Turks and Caicos (UK), United States of America, Venezuela **North America:** Canada, Mexico, United States of America
Oceania (10 of 25 countries)	Australia, Cook Islands, Fiji, French Polynesia (FR), Guam (USA), New Caledonia (FR), New Zealand, Papua New Guinea, Tuvalu, Vanuatu

*not an FAO member nation as of Feb 2010 (http://www.fao.org/countryprofiles/flags.asp?lang=en);
Underlined countries not divided into administrative subunits; *Italics* not included in FAO statistics as of 2009 (FAO 2009b).

Next, we acquired electronic production statistics from official annual statistical yearbooks, databases, and reports at the country or regional level. Supplementary statistics were also collected from published government, academic and other specialist literature. If production statistics were not freely available online, relevant authors were either contacted for data or statistics were obtained in a hardcopy format courtesy of local and international collaborators (see Acknowledgements). Wherever possible, annual production statistics, in or converted into metric tonnes whole (wet) weight, were collected at sub-national levels (e.g. provincial or state level) and by species (See Appendix to Chapter 2: Table A.1).

A rule-based estimation methodology was used to fill data gaps when production statistics were either not publically accessible or available (Table 2.3), or were not at the desired resolution (Table 2.4); this included linear interpolation between years and conservative estimates for years preceding available data.

Table 2.3: General production estimation procedure for GMPD database, where official data were not available or accessible.

	Estimation Issue	**Interpolation Method**
1	Production missing for 5 years or less at beginning or end of dataset but is known to occur	Assume production for the missing year(s) is the same as the last year with data
2	Production is missing in one year, between years, within the dataset	Take an average of year previous and year subsequent to the missing year
3	Production is missing for between 2 and 10 years, between years, within the dataset	Use linear rate of increase or decrease in production between year previous and year subsequent to missing data: $X_{t+1}=X_t + \lvert X_{Final} - X_{Start}\rvert / (n+1)$
4	Production is missing for more than 10 years within the dataset, or more than 5 years at the beginning or end	Supplement with FAO FishStat Plus (v.2.3.1) or Eurostat online database (FAO 2008a; EC 2010)

In particularly data-poor situations, i.e., the years prior to 1970, when the mariculture industry of most countries was in its infancy, FAO FishStat Plus data (v.2.31), and those in (Pullin *et al.* 2007) were used as a starting value for estimation, so as to obtain a consistent data set starting in 1950.

Table 2.4: Spatial and taxonomic production estimation procedure for GMPD database. Where reported production for given taxa in a given year varied between different reporting agencies in the same country, the estimates were averaged.

	Estimation Issue	Interpolation Method
1	Production exists at mostly only the country level or broader taxonomic classification. Limited production data are provided for administrative subunits or for individual species for some years.	Use ratio - Assume production by subunit or species is directly proportional to production by country or broader taxonomic classification. Use the ratio of production derived from years with complete data to estimate missing production by subunit or species
2	Production exists at mostly only the country level or broader taxonomic classification. Limited percentages of total production have been provided for administrative subunits or for individual species for some years.	Use percentage ratio - Assume production by subunit or species is directly proportional to the percentage of production by country or broader taxonomic classification. Use the ratio of production derived from years with complete data to estimate missing production by subunit or species
3	Production exists at only the country level in a given country.	If searched literature does not explicitly state that production occurs in only one region, divide reported production evenly among all coastal regions
4	Production in a given country is aggregated into broader taxonomic classifications or "Other" categories.	Search literature for names of additional species produced as well as for quantities or percentages of production If literature does not specifically state production information but provides names of additional species produced, divide aggregated production evenly among all additionally identified species If no suitable data is found, leave production in broader categories
5	Some or all years of production are missing for a particular species that the literature suggests is produced in a given country or administrative subunit.	Use FAO FishStat Plus or Eurostat online data, followed by the appropriate interpolation method described above

2.2.2 Spatial mapping of data

To provide a visual time-series representation of global mariculture production trends, we generated a spatial database, which could be visualized through a GIS. This database can be used to show the geographic history of the production and expansion of taxa across each country's coastal provinces, as reported in that country's mariculture statistics and/or supplementary data. With respect to representing the area of ocean from which the production originated, the production figures were not assigned to specific locations (e.g., as determined by coordinates of latitude and longitude), but instead to a coastal stretch within the Exclusive Economic Zone of the country in question (or province) in question, within what we call the Inshore Fishing Area (IFA). The IFA corresponds to that part of the continental shelf (i.e., waters not deeper than 200 m) that is within 50 km distance from the shore (Chuenpagdee *et al.*

2006). As defined, the IFA of countries is under pressure from both industrial and small scale fisheries, and also currently includes the production facilities of all extant mariculture operations in the world.

2.3 Results

A total of 67,284 records of global mariculture production were collected for the GMPD database from 1950 to 2004. This represents a combined total of production data for 261 unique taxa (183 at species level), produced in 112 coastal countries across 663 different 'provinces' since 1950.

2.3.1 Comparison between GMPD and FAO

The global mariculture production generated by the *Sea Around Us'* GMPD dataset is very similar to the analysed subset of FAO Fishstat Plus (v.2.31) Aquaculture Production dataset (FAO 2008a) over the entire time series (Figure 2.1). In both datasets, global marine and brackishwater fish production more than triples between 1950 and 1970. Since 1970, annual rates of production increase are also very similar between the FAO and *Sea Around Us* datasets, with and without China included in analysis. However, in 2004, the difference between the two datasets amounted to 4.6 million tonnes, with the GMPD reporting the larger figure of 23.7 million tonnes. When China is excluded, the FAO reports the larger figure by 394,000 tonnes.

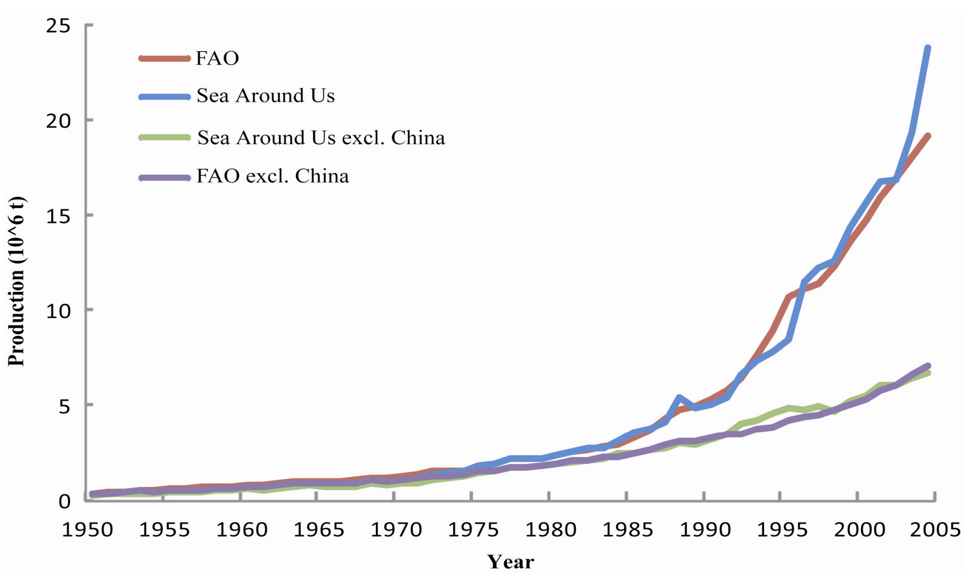

Figure 2.1: Comparison of mariculture production trends between the FAO and the *Sea Around Us'* GMPD datasets, with and without China included in analysis. Exponential regressions for the years 1970 to 2004 yield similar slopes, suggesting a mean global rate of production increase of 8.6 % per year with China and 5.5 % per year without China.

Two main sets of differences become apparent between the global mariculture production data trends when the time-series are analyzed in greater temporal detail. The first occurs in the data-poor years between 1950 and 1970, when the average annual production reported by FAO FishStat Plus v.2.31 (FAO 2008a) is 127,000 tonnes greater than reported in the GMPD database, whether or not China is included in the analysis. The GMPD's average annual production (including China) during these years is 666,000 tonnes. The second set of differences occurs between 1996 and 2004, when the average annual tonnage in the GMPD, including China, is 15.9 million tonnes and greater than the FAO dataset by 1.1 million tonnes annually. GMPD production is an annual average of 234,600 tonnes greater when China is excluded. At the global scale, eleven years between 1950 and 2004 have productions differing by more than 20% between datasets; in all but two cases these differences occur in the data-poor years prior to 1970 and the GMPD production figures are the more conservative.

A regional time series comparison of FAO and GMPD data trends yields an overall similarity in production trends in some regions, and observable differences in others (Figure 2.2). The largest regional discrepancies were also found prior to 1970, where again the GMPD provided the more conservative production estimate. The regions with the smallest annual relative differences in production between datasets were Europe and Asia (without China). Prior to 1985, the regions with the largest annual relative differences in production were Oceania and the Americas; however, these annual differences have declined to negligible amounts (<10%) since the mid-1990s and the differences between African datasets has increased considerably, with the GMPD reporting an annual average of 44,700 tonnes fewer than the FAO since 1998.

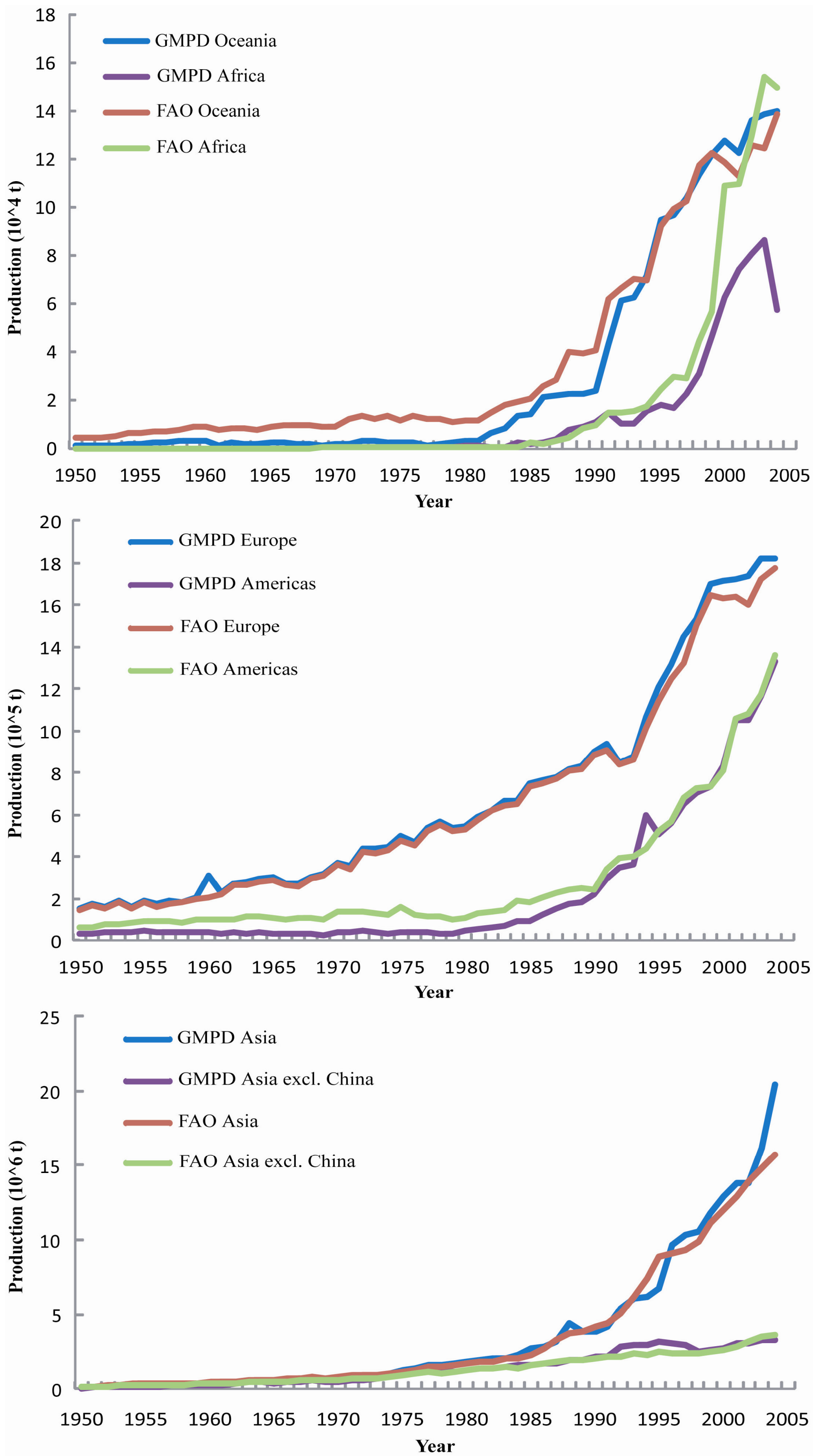

Figure 2.2: Regional comparison of mariculture production trends between the FAO and the *Sea Around Us*' GMPD datasets for Oceania and Africa (top), Europe and the Americas (middle) and Asia with and without China (bottom). Note that the ordinate scales differ between the three panels of this figure.

When global production (including China) is compared by major taxonomic groups, there is also a strong similarity in production trends, with a few exceptions (Figure 2.3). Mollusks, for instance, a grouping composed primarily of bivalves (this analysis excludes a negligible production of cephalopods and gastropods), account for roughly 75% of all mariculture production by volume worldwide since 1970 (recall that marine plants are also excluded). A time series comparison of data trends for mollusks therefore strongly resembles the comparative trends of total global production (Figure 2.3b and Figure 2.1). The finfish group, with global production increasing more than twentyfold between 1970 and 2004, shows an observable difference between datasets from 1992 to 1997. In this period, GMPD reports an annual average finfish production of 2.05 million tonnes, or 636,000 t more than the equivalent FAO dataset. Reported trends in crustacean production in both datasets are similar, with a consistently observable difference in production after 2002. In both datasets, the annual production of crustaceans grew by 18% between 1970 and 2002, representing a 185-fold increase from the GMPD's reported global production of 9,088 tonnes in 1970. In 2003 and 2004, FAO reported production of crustaceans is on average 490,000 t greater, or 2.67 million tonnes in 2004 (FAO 2008a).

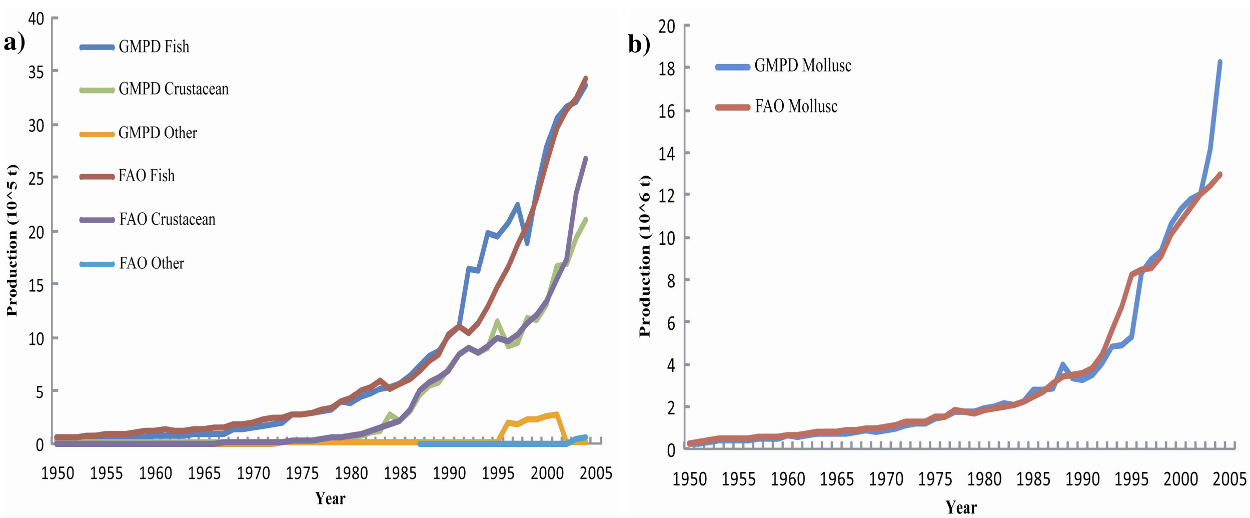

Figure 2.3: Comparison of mariculture FAO and Sea Around US GMPD datasets, by major taxa. **a)** Fish and Crustaceans; **b)** Molluscs. Note that the production of this group is greater by a factor of ten. 'Other' species such as pearl oysters and invertebrates such as urchins and sea cucumbers are included in the GMPD, but not in this analysis.

Although the overall time series trends of global production by major taxonomic group remain largely comparable between datasets, since 1975 the *Sea Around Us* Project database (GMPD) has assigned production to an average of 21 more taxa annually than the equivalent FAO dataset (Figure 2.4).

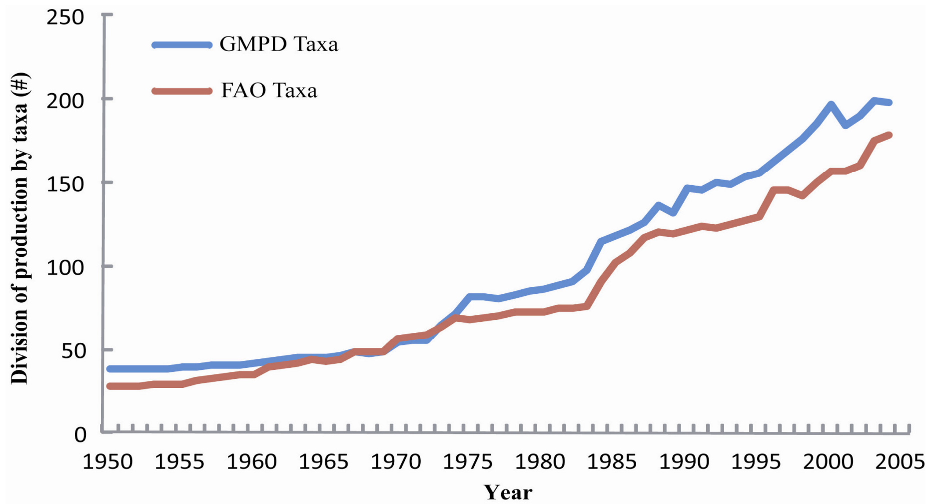

Figure 2.4: Difference in the total number of taxa to which mariculture production is assigned in each year. This increasing trend is atributable to a temporal increase in the number of species produced as well as to a gradual improvement in the detail of reported data worldwide.

The taxonomic organization and composition of each dataset differs; this complicates species-to-species comparisons between the two datasets. The GMPD database does report production for an additional 6 taxa as of 2004, all of which are bivalves (Appendix to Chapter 2: Table A.2).

2.3.1 Farming up the food web

As the total number of taxa reported as produced over time has increased, so too has the mean annual trophic level of the species produced since the 1970s. This phenomenon has been described as "farming up the food web" (Pauly *et al.* 2001b; Stergiou *et al.* 2008; Tacon 2010). Trophic levels (TL) describe the relative position of a species in the broader aquatic food chain and are described by the following equation: $TL_i = 1 + \sum_{j=1}^{G} DC_{ij} \times TL_j$

Where TL_i is the trophic level of species (i), TL_j is the trophic level of prey (j), DC_{ij} is the contribution of prey (j) in the diet of species (i) and G is the total number of prey (Froese and Pauly 2000; SAUP 2009). A trophic level of 2.0 represents an herbivorous species, while intermediate predators begin at around TL 3.1 and top predators have TL values greater than 4.1 (Stergiou *et al.* 2008). In the absence of an aquaculture-specific trophic index, where the TL of farmed species would be computed based on the trophic level of their feed (which can be computed only given a knowledge of its composition, which implies knowing its origin), the analysis below was performed using TL estimates derived from the wild species in question, as given in FishBase (www.fishbase.org). Given that farmed higher-TL species are fed diets rich in animal protein and oils, and lower TL species are fed comparatively little or no animal inputs, wild and captive TLs will be correlated (Pullin *et al.* 2007); this logic is assumed in our analysis of 255 of the 261 species included in GMPD database.

An analysis of these taxa indicates that the weighted mean TL of taxa produced in marine and brackish environments has increased since 1950 (Figure 2.5a), i.e., it has risen from 2.03 prior to 1970 to a maximum of 2.46 in 1994, and is 2.38 in 2004. This is the global TL equivalent of shifting from the production of mussels (*Mytilus* sp.) to So-iuy mullet (*Mugil soiuy*). “Farming up the food web” is also apparent at a regional scale; all regions show a trend of increase in the weighted mean TL of production since 1980 (Figure 2.5b). However, since the 1990s, some regions have experienced either a decrease or a leveling off of their weighted mean TL.

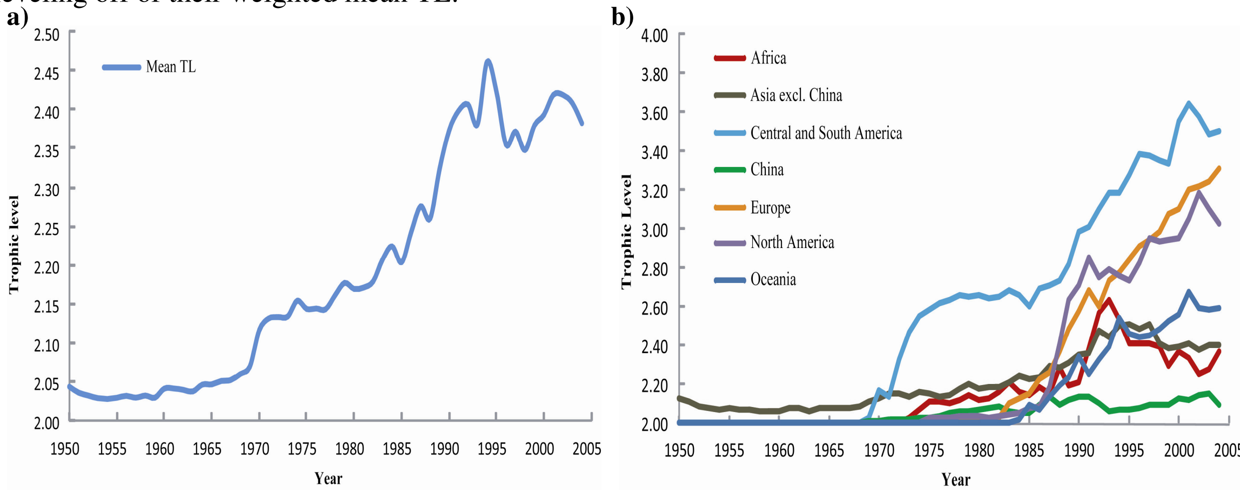

Figure 2.5: a) Temporal change in the weighted mean trophic level (TL) of mariculture production in the GMPD, demonstrating “farming up the food web”; **b)** Temporal change in the weighted mean TL of mariculture production in the GMPD, by region.

An analysis of GMPD production trends by TL class between 1980 (when industrial mariculture production took off) and 2004 indicates that the annual rate of growth of the production of intermediate predator species (trophic levels 3.1 to 4.0), such as *Sparus aurata* and *Dicentrarchus labrax*, is 14.6 %. The weighted mean TL of species produced in this trophic class in 2004 was 3.63. In this same time period, the production of top predators such as *Seriola dumerili*, *Thunnus thynnus*, and *Salmo salar* (TLs equal to or greater than 4.1) grew at a rate of 28.3%. The weighted mean TL of species produced in this trophic class in 2004 was 4.28. Although herbivorous and omnivorous species such as *Crassostrea gigas, Mytilus edulis,* and *Penaeus monodon* are produced in quantities an order of magnitude greater than those of carnivorous species, the annual rate of production growth in this trophic class was only 9.6% between 1980 and 2004. In 2004, the weighted mean TL of species produced in this trophic class was 2.20.

2.3.2 Spatial regional trends

Figures 2.6-2.10 illustrate the average annual mariculture production of countries by major global region between 2000 and 2004. Asia, both including and excluding China, has consistently produced the largest quantity of farmed marine and brackish species worldwide since 1950. Figure 2.6 shows where, in 2000-2004, Asia's mariculture is concentrated. Note that while finfish and crustacean production is substantial in Asia, particularly with respect to tiger prawn (*Penaeus monodon*) and milkfish (*Chanos chanos*), regional mariculture production has been consistently dominated by bivalves.

Northern Europe (Figure 2.7) is also a global production centre for mariculture. Average production in the early 2000s is concentrated primarily in Norway, the United Kingdom, and France and is dominated by finfish such as Atlantic salmon (*Salmo salar*), saltwater-reared rainbow or 'sea' trout *(Oncorhynchus mykiss* and *Salmo trutta*), and bivalves such as blue mussel (*Mytilus edulis*) and Pacific cupped oyster (*Crassostrea gigas*).

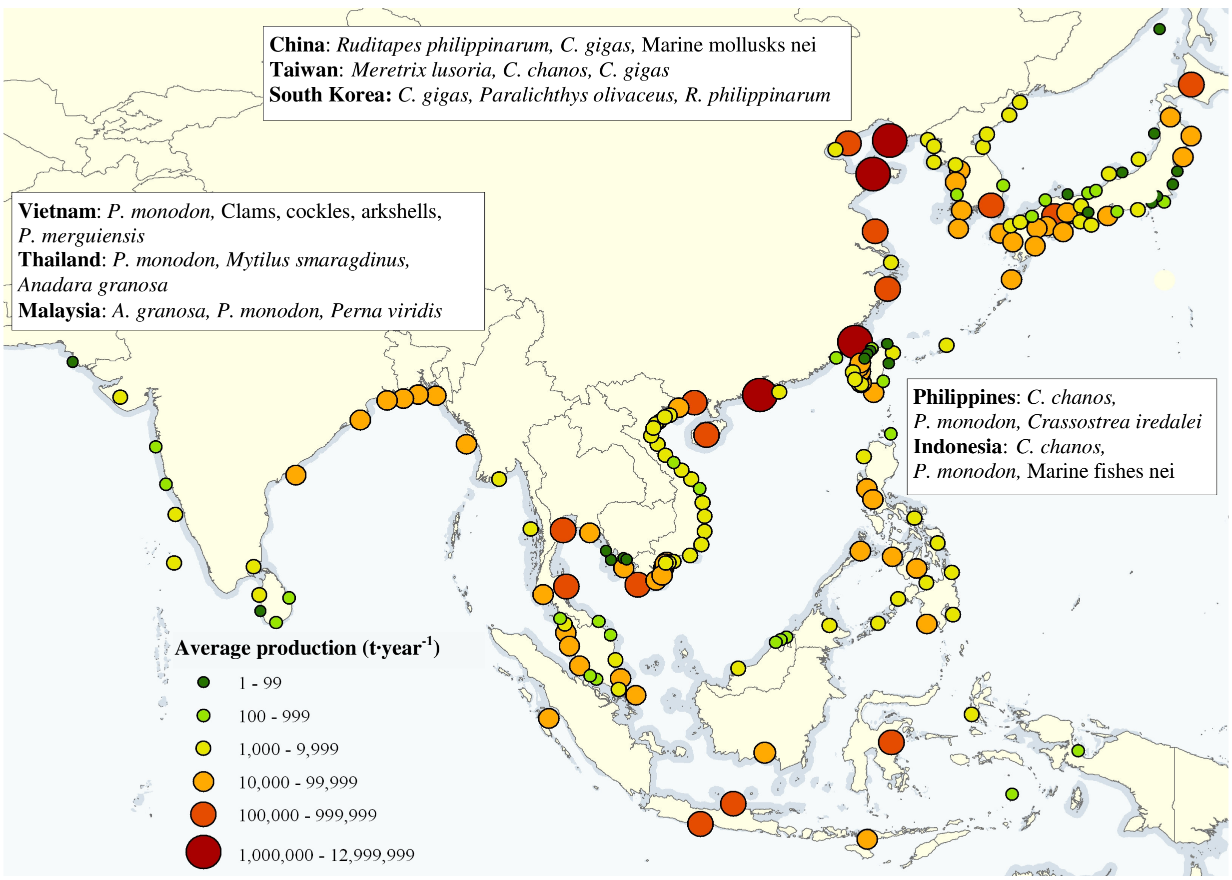

Figure 2.6: Mean annual mariculture production (t) in Asia from 2000 to 2004. Inshore Fishing Area (IFA) is represented along the coastline in blue. The text boxes contain the top 3 species produced in the period 2000-2004 for major producing countries. Asia west of Pakistan is not shown here, as mariculture development and production are negligible.

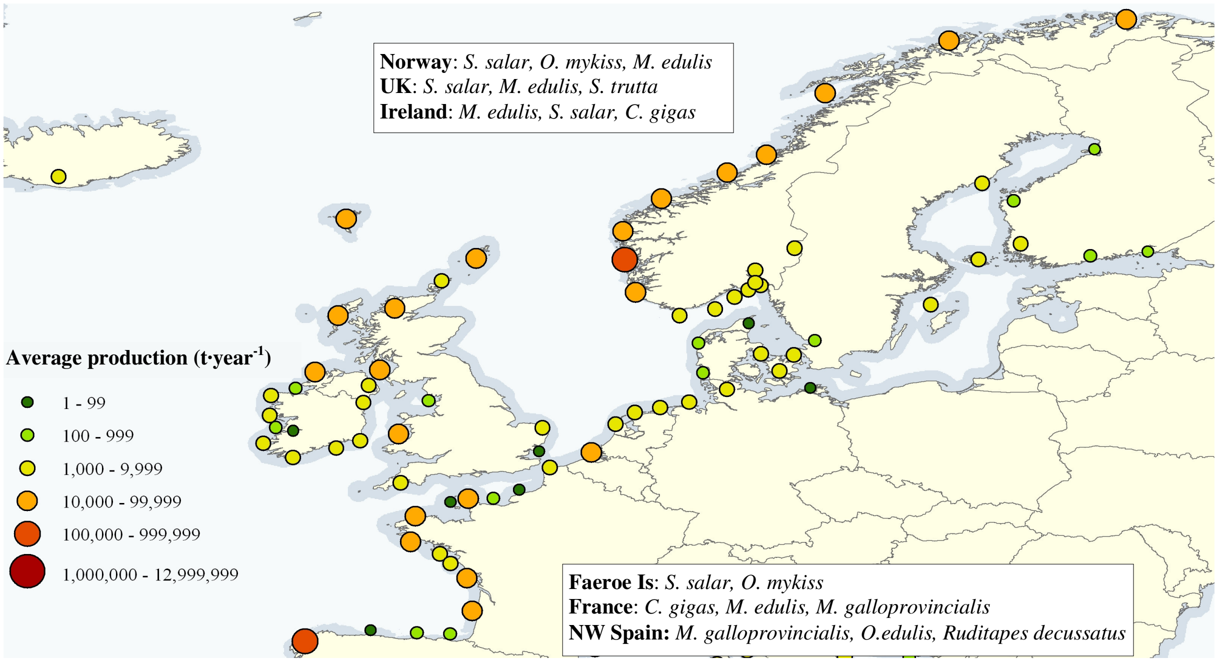

Figure 2.7: Mean annual mariculture production (t) in Northwestern Europe from 2000 to 2004.

Although the Mediterranean is also a major global production centre for mariculture (Figure 2.8), unlike in Asia and Northern Europe, not one province exceeds an annual average production of 100,000 tonnes between 2000 and 2004. Production in this region is dominated by Mediterranean mussel (*Mytilus galloprovincialis*), European seabass (*Dicentrarchus labrax*) and gilthead seabream (*Sparus auratus*).

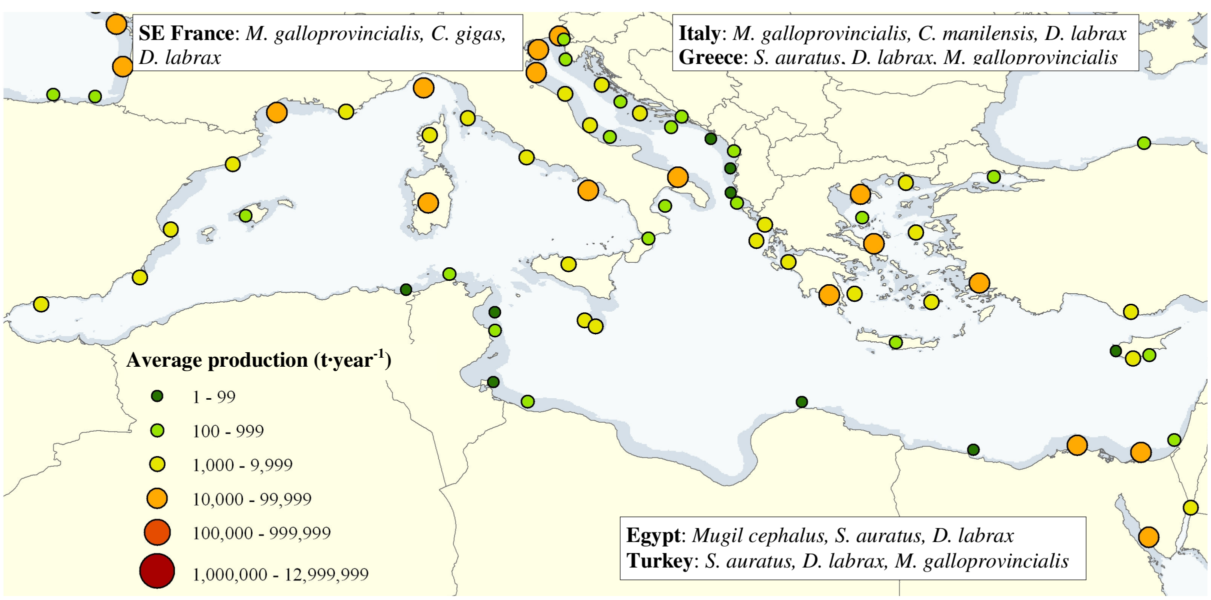

Figure 2.8: Mean annual mariculture production (t) in the Mediterranean from 2000 to 2004.

In North America (Figure 2.9), Canada and the United States of America are major global producers of both Atlantic and Pacific (*Oncorhynchus* spp.) salmon as well as of bivalves such as blue mussel, cupped oysters (*Crassostrea* spp.), and hard clam (*Mercenaria mercenaria*). As of 2000, Mexico's commercially most important species were penaeid prawns and Pacific bluefin tuna (*Thunnus orientalis*); these are farmed primarily in the North-west. The Caribbean, Central and South America have a widespread, but collectively lower production, with a few production hotspots in Ecuador (white shrimp *Penaeus vannamei*), Brazil (rock mussel (*Perna perna*) and *Crassostrea* spp., as well as white shrimp), and Chile, a major producer of Atlantic salmon (Figure 2.10).

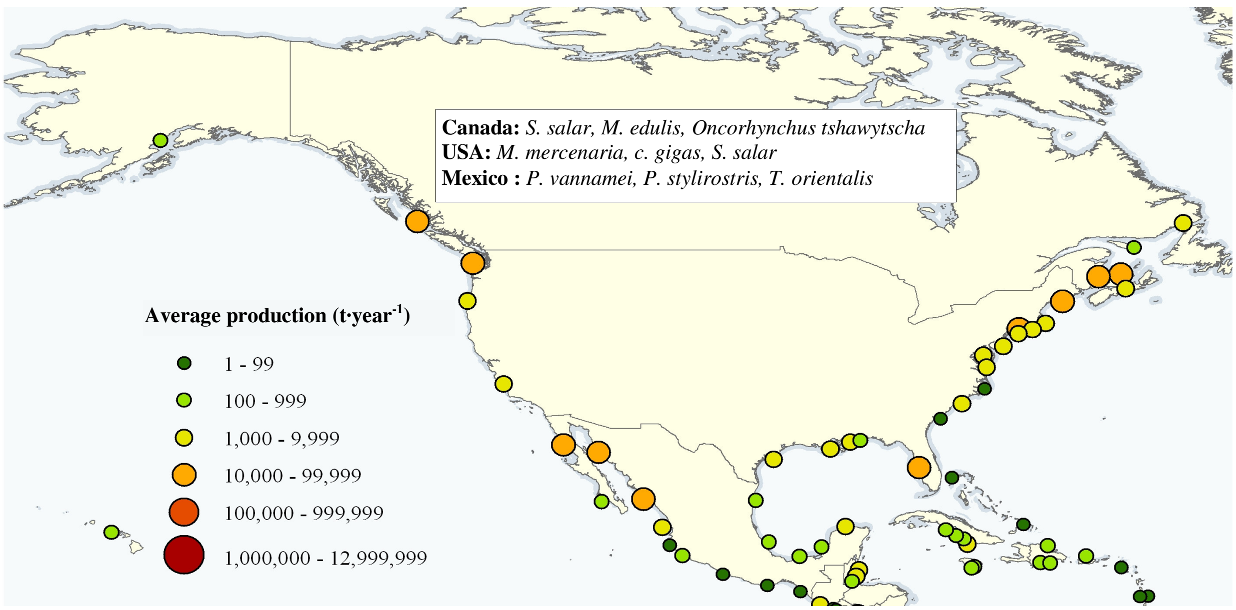

Figure 2.9: Mean annual mariculture production (t) in North America from 2000 to 2004.

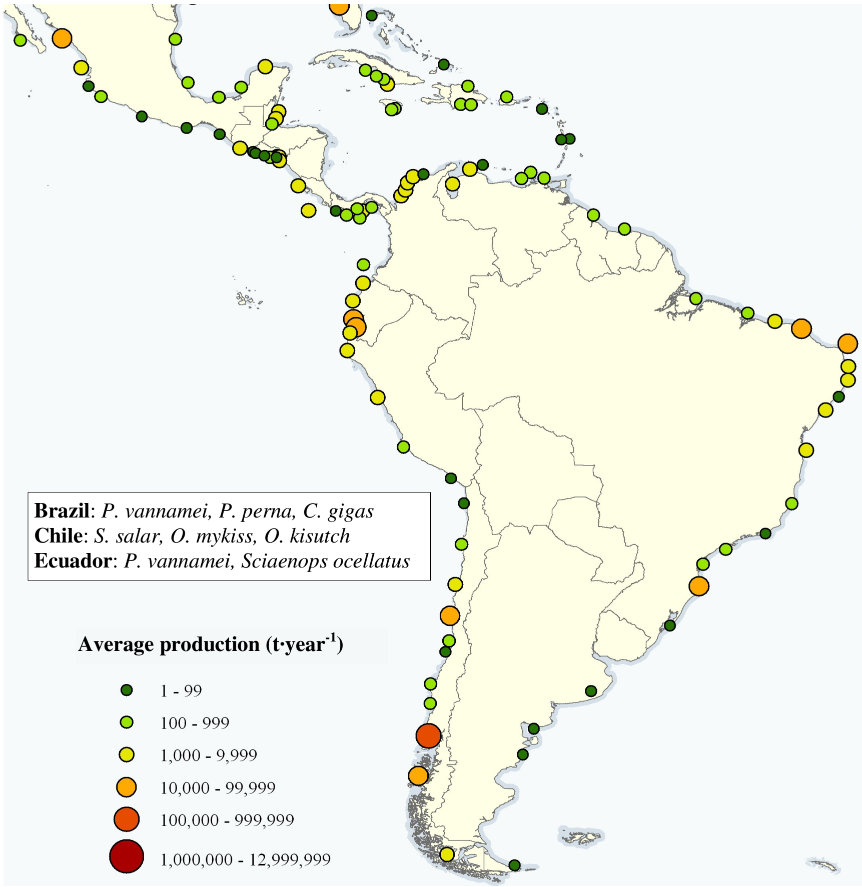

Figure 2.10: Mean annual mariculture production (t) in the Caribbean, Central, and South America from 2000 to 2004.

2.3.3 Country-level trends

Between 1980 and 2004, a decline in mariculture production occurred in three countries worldwide (Malaysia, The Netherlands, and Senegal). Two countries (Chile and Norway) experienced an increase in production of between 500,000 and one million tonnes between 1980 and 2004. Only China reported an increase in production greater than one million tonnes; between 1980 and 2004, Chinese mariculture production reportedly increased by 16.6 million tonnes.

With respect to China, by far the world's largest contributor to mariculture production, two of the country's top four mariculture-producing coastal provinces produced more, when combined, than any other country between 2000 and 2004 (Figure 2.6). These Chinese provinces have experienced production increases of more than five million tonnes since 1980 and reported an annual average production in excess of one million tonnes from 2000 to 2004. This production consisted predominantly of bivalve species; thus, in contrast to the rapid increase in weighted mean TL occurring in most regions of the world in the 1990s, China's weighted mean TL has remained relatively stable since the mid-1980s. Chinese mariculture production reached its maximum mean TL of 2.15 in 2003 - the trophic level equivalent of the razor clam *Pharus legumen* or flathead mullet (*Mugil cephalus*), which feed on detritus (Blaber 1976).

In analyzing the mean trophic level trends of other countries, a negative absolute change in the weighted mean trophic level of mariculture production occurred between 1980 and 2004 in 11 countries (Brazil, Denmark, Finland, Germany, China-Hong Kong SAR, Japan, Nigeria, Norway, Peru, Singapore, and the United Kingdom), i.e., the weighted mean TL of species produced in these countries was higher in 1980 than in 2004. This means that these countries are presently producing larger quantities of lower TL (herbivorous and omnivorous) species than they were in 1980. Nine countries (Bangladesh, Sri Lanka, Colombia, Ecuador, Honduras, Korea DPR, the Netherlands, Panama, and Senegal) experienced no overall change in the weighted mean TL of species produced between 1980 and 2004. Eleven countries increased the weighted mean TL of their farmed species to more than 3.01 (Bahrain, Bosnia Herzegovina, Cambodia, Cyprus, Israel, Kuwait, Libya, Mexico, Montenegro, Oman, and Turkey) and four countries have a mean TL increase to more than 4.01 (Iceland, Malta, Mayotte, and Martinique). All countries with a TL increase to over 3.01 had no reported mariculture production in 1980.

Assembling and analyzing mariculture production statistics at a sub-national level led to the identification of production data that do not appear to be currently reported by the FAO. These additional data were located for 27 countries between 1977 and 2004 (Table 2.5). When compared to global production, however, this additional production is negligible, amounting to <1% of total global production for any given year, or 12,670 tonnes in total for all years of additional data found. The majority of this additional production occurred in the mid-1980s through to the late 1990s, notably in Oman, Libya, Croatia, and Cambodia.

Table 2.5: List of production unaccounted for by FAO. Production greater than 1000 tonnes is in bold. Montenegro was not listed separately by the FAO at the time of this analysis					
	Country Code	**Country**	**Region**	**Years Added**	**Total Production (t)**
1	887	Yemen	ME	1988 - 2004	16
2	784	UAE	ME	1990 - 2002	28
3	705	Slovenia	E-MED	1986 - 1991	172
4	630	Puerto Rico	CA-NA	1995	32
5	634	Qatar	ME	1998 - 2000, 2002 - 2004	4.5
6	626	East Timor	AS	1989 - 1997	195.5
7	586	Pakistan	AS	1985 - 1987,2001	197.5
8	548	Vanuatu	PAC	2004	0.1
9	512	**Oman**	ME	1999 - 2002	**1177**
10	508	Mozambique	AF	2001	600
11	499	*Montenegro*	E-MED	1988 - 2004	352
12	484	Mexico	NA	1984	6
13	480	Mauritius	AF	1977 - 1983	77
14	474	Martinique	NA-E	1988	1
15	470	Malta	E-MED	1990	60
16	434	**Libya**	AF-MED	1991 - 2003	**1428**
17	422	Lebanon	ME-MED	1997 - 2003	79
18	414	Kuwait	ME	1990, 1991, 1993, 1994	3
19	191	**Croatia**	E-MED	1980 - 1991	**5197**
20	184	Cook Is.	PAC	1986 - 2004	200
21	175	Mayotte	AF-E	1998 - 2002	779
22	116	**Cambodia**	AS	1988 - 1992	**1634**
23	111	Eritrea	AF	1999 - 2004	260
24	100	Bulgaria	E	2001	7
25	96	Brunei D	ME	1989, 1991	1
26	84	Belize	CA	1984-1988	161
27	48	Bahrain	ME	1994	1.5

The FAO reported mariculture production as occurring in five more countries than the GMPD dataset. Two of these countries, Estonia and Gambia, are excluded from the scope of analysis in the GMPD database, having no active commercial production in 2004. The additional three countries, reported as producing fewer than a total of 20 tonnes in 2004, are Tonga, Kiribati, and Palau (FAO 2008a). These South Pacific islands of Oceania were excluded from GMPD analysis because the literature obtained for these countries did not clearly indicate that production was in fact for human consumption and not for hatchery restocking, the marine aquarium trade, or for capture fisheries (SPC 1998; Adams *et al.* 2000; FAO 2002a; FitzGerald Jr. 2004).

2.4 Discussion

2.4.1 Interpretation and limitations of analysis

The similarity between the FAO and *Sea Around Us* global mariculture production - which is in stark contrast to the situation with marine fisheries catches - is encouraging, and might be attributable in part to key characteristics of the industrial mariculture sector. This sector is predominantly focused on commodity-driven and export-based production, under conditions of private ownership. With limiting economic and institutional resources, countries may be more amenable to investing in reliable statistical information systems for tracking market commodities with the above characteristics than they might be for those with a larger domestically-traded, lower-value, or subsistence production component (as is often the case in fisheries catches, or at least the fraction that has yet to be adequately accounted for). Within the mariculture sector itself, statistics for commercially higher-value species such as prawns and carnivorous finfish were in general much easier to obtain than for other groups, and, unlike lower-value bivalves, were more often reported at species level. Moreover, the majority of aquaculture's lower-value, domestically-traded, and more small-scale production occurs in freshwater, inland environments (FAO 2010c). It has been estimated that one-sixth of such production is ever officially reported (Silpachai 2001).This has implications for the potential accuracy for the global outlook of aquaculture as a whole, i.e., including freshwater aquaculture. However, this is beyond the bounds of the present analysis.

While the FAO does not explicitly publish their aquaculture data processing methodology (FAO 2009b,2010c), another potential reason for the overall similarities in compared mariculture production trends may be a result of similar global data accessibility and a resemblance between and FAO and *Sea Around Us* data estimation methods. With the GMPD dataset, obtaining mariculture production data for some countries, taxa, and years was relatively straightforward; however, approximations were required where it was not. These approximations increase uncertainty in the both the global and regional production trends outlook. The effects of this uncertainty are most easily illustrated in looking at the strong similarity between compared GMPD and FAO regional production trends in Europe, where production data were reasonably accessible and required relatively low estimation across the entire time series, in the improvement in comparability over time between trends in Oceania, owing primarily to an increase in the availability and accessibility of statistics, and in the discrepancy between compared production trends in Africa, where data availability and accessibility remains poor and the need for estimation is high. With respect to the GMPD dataset, a strong reliance on electronic media made accessing production statistics challenging when governments did not respond to requests. With respect to the FAO, although this organization has a better access to data worldwide, reporting compliance from member countries remains moderate at best, often necessitating further work or estimation on the part of the FAO (FAO 2002b). The FAO estimates that the average annual response rate for countries reporting aquaculture production is around 60%, an improvement from the early 1990s where the average response rate from countries was 40% (FAO 2005b). Prior to 1985, when FAO aquaculture statistical collections first began (FAO 2009b), aquaculture production statistics were often part of a more general set of fisheries statistics. It is thus encouraging that our global reconstruction and that of the FAO roughly match each other.

However, it is possible that both databases may suffer from the same inaccuracies. One such issue relates to the questionable accuracy of Chinese aquaculture production statistics, a subset of a larger issue with the statistics it generates (Pang and Pauly 2001; Batson 2010). China has been the single largest global mariculture producer for more than two decades and is the world's leading exporter of seafood and fishery products since 2002 (Pan 2005). Despite this country's significant role in both fisheries and aquaculture, obtaining reliable production statistics for China is a recognized challenge, one which the FAO continues to address (*Zhijie et al. 2008*). In spite of the broad match between the GMPD dataset and FAO production trends, it is still uncertain how accurate either dataset is at representing the 'true' state of mariculture production in China. Adding to this uncertainty, the reported production of bivalves in China, which comprise a significant proportion of national (and therefore global) mariculture production, was erroneously reported prior to 1996 as well as in the recent past, due to discrepancies in whole and live weight conversion factors for three of their major bivalve species (Rana and Immink 2001). Despite corrections made to FAO datasets to compensate for these and other reporting errors, and a change in Chinese reporting protocols after 1996, these problems with Chinese aquaculture statistics lead to doubts about the accuracy of global mariculture production trends, because of China's significant contribution to them. This, indeed, is the reason why the FAO reports global aquaculture information both with and without China (FAO 2010c), and why it is not prudent to base statistics such as global per capita consumption of aquaculture products, or the ratio of seafood from aquaculture to fisheries catches on data including China.

The second cause for a critical evaluation of the accuracy of mariculture's overall global production trends relates to a lack of clarity in some aspects of the statistical reporting process at the national and international level. Due in part to aquaculture's rapid rate of worldwide growth and expansion and to the relative newness of commercial-scale industry in many countries, the development and maintenance of statistical systems for aquaculture has not kept pace with a growing and diversifying demand for data (Nash 1988; FAO 2005b,2008e). This lack of clarity arises primarily from the fact that in the statistical reports of many countries, the contents of which are submitted to the FAO for compilation and analysis, there is often a lack of transparency in terms of what is and is not being reported as 'aquaculture', if reported at all.

Some of this confusion arises from ambiguities in the statistical definition of aquaculture. Following the FAO's establishment of aquaculture statistics distinct from those of capture fisheries, the FAO has developed a handbook of standardized definitions and concepts to which countries can commonly adhere in their diverse reporting frameworks (FAO 2010a). However, in practice, the interpretation of these definitions varies between countries. Thus, for example, it remains unclear how certain farming practices distinguish themselves from capture fisheries, particularly when rearing techniques are extensive and involve few outside inputs. Given that these extensively-produced coastal species, e.g., bivalves such oysters and clams and brackishwater finfish such as milkfish (*Chanos chanos*), are produced in large quantities worldwide, the interpretation of reported production as either fisheries catch or mariculture harvest in statistical reports has the potential to affect global, regional, and country-level status and trends of both fisheries catch and mariculture production.

This issue also occurs among some of the highest-priced species, such as salmon, prawn, and tuna. With respect to tuna, which are wild caught as juveniles, contained in pens at sea, and reared with artificial feeds, the 'fattening' or 'ranching' of this species is technically defined as an "enhanced capture fishery" in the CWP handbook of Fishery Statistical Standards (FAO 2010a); however, it is also referred to as "capture-based aquaculture" in other FAO documents (Lovatelli and Holthus 2008). In practice, it is unclear how these farming activities are ultimately accounted for, if at all, in the production statistics of many countries (FAO 2005b,2005a; Volpe 2005; Bregazzi 2007; Ottolenghi 2008; Black 2010). This lack of definitional clarity has likely contributed to some of the global and regional discrepancies in mariculture production between GMPD and FAO datasets. With respect to the impact of this issue on global production trends, it is possible that trends reported by the FAO prior to 1970 represent an overestimate of actual mariculture production due to the inadvertent inclusion of capture data for bivalves and brackishwater finfish. Conversely, the difficulty in obtaining a usable estimate of 'aquaculture' production prior to 1975 means that the GMPD database's conservative trend of global mariculture production possibly represents an underestimate of actual production during these decades.

Another source of confusion in clearly interpreting production statistics is the lack of standardization in the statistical reporting structures at the country level. In addition to differently interpreting the definition of aquaculture, some countries (several of which are major producers, such Japan, the Philippines and

Greece), appear to omit the production of species farmed in minor quantities entirely from official statistical yearbooks. It is likely, given that small amounts of additional production data were found for a number of countries in the GMPD dataset and that data accessibility was a common issue when collecting data, that production underreporting is globally widespread. However, it is difficult to estimate how much this underestimation may affect global mariculture production trends.

In other countries, such as in the USA and Canada, production is deliberately reported as an estimate or taxonomically aggregated in annual yearbooks in order to maintain privacy for farm owners. Some countries report production in different units of measure than FAO convention, such as "bushels" or gutted weight, increasing the likelihood of error in conversion and interpretation. In the most extreme cases, data are aggregated into such broad categories as to be unusable for all but the most basic analyses, such as "meat fish" listed in Cambodian aquaculture statistics. It has been observed that 21.2% of total aquaculture production in 2000 was reported in non-specific categories, with finfish and (primarily marine) mollusks representing two of the major categories with the greatest non-specific reporting (Tacon 2000). Adding to the taxonomic challenge of correctly attributing production to a given species is the fact that while the FISHSTAT AQ reporting forms include a column for recording the scientific names of species produced (FAO 2010a), the FAO presents global production data publically in a common-name format, as opposed to scientific names. Most countries appear to have followed suit, with the added source of confusion that they use country-specific common names, instead, e.g., of FAO common names, which have at least been standardized for English, Spanish and French.

Although it is prudent to be aware of uncertainty when examining global, regional, and country-level mariculture production trends, the dramatic worldwide increase in production in a few short decades is indisputable. What is also evident is the temporal trend of global increase in the weighted mean trophic level of mariculture production, indicating "farming up the food web" (Pauly *et al.* 2001b; Stergiou *et al.* 2008). That the weighted (by production) mean trophic level remains within low trophic levels is due to the bulk of global mariculture production consisting of bivalves with a TL of 2 and omnivorous, brackish finfish with TLs between 2.1 and 3. However, there is also a considerable upward 'pull' from greater quantities of high-trophic level finfish being farmed worldwide since 1980. Another reason for this result is that our trophic levels are derived from feeding habits in the wild, and not from artificial feed (which may contain meat or fish meal). Computing the TL of feed, as stated above, is a complicated undertaking, and was not attempted here. We note however, that our results yield a TL range (2.4-2.75) that is similar to the TL obtained in an analysis of all aquaculture environments over the same time period by Tacon *et al*. (2010).

2.4.2 Implications and emerging trends

The GMPD database represents only a first step in the taxonomic and spatial refinement of global mariculture data. However, by attributing production in a given country to smaller geographic units through a global scale GIS, as done here for the first time, additional information is provided for analyses and policies that address issues of coastal ecosystem stress and modification, of food production and further industry expansion and development, and of interactions with capture fisheries. This work also confirms areas where additional improvements to the quality of aquaculture data are still needed in order to fulfill the principles of collecting the 'best available data' in accordance with the *Code of Conduct for Responsible Fisheries* (FAO 1995), and where caution should be taken when interpreting trends.

In this regard, while it is likely that the global and regional production trends reported by the FAO provide a reasonable estimate of historical mariculture production trends (thereby reducing one source of information uncertainty), there are indications in reported statistics and additional supplemental information that mariculture production is being underreported in some countries by as-of-yet unknown amounts. Thus, the likely accuracy of mariculture production statistics should be considered for a given country before its reported trends can be evaluated. This means that while it is possible that more food fish is being produced (at least outside of China) than is currently thought, it also means that more environmental resources are being used to produce these fish. Ultimately, while some of mariculture's trends and relationships are better defined as a result of this work, others remain just as uncertain; it therefore remains difficult to determine the true economic, social, and environmental impact of the mariculture industry worldwide.

The spatial production maps produced to complement the GMPD provide a visual tool for displaying the current reach of mariculture along the coastal zone of maritime countries. Despite ongoing issues of data accuracy, the taxonomic and geographic resolution of reported data is gradually improving worldwide. This analysis highlights more than three decades of increasingly rapid global mariculture production growth, as well as the growing focus on increasing the diversity and production of higher trophic level finfish species such as salmonids, seabasses, and tuna.

Looking forward, further increases in global mariculture production do not appear to be geographically constrained in the short term, particularly given the recent emergence of both onshore and offshore mariculture production facilities. However, analysed results indicate that rates of growth in regions with more historically established production sectors, such as Europe and Asia excluding China, appear to be slowing down. This trend has also been observed by others (Liu and Sumaila 2008; FAO 2010c).

Moreover, in some regions such as sub-Saharan Africa, Oceania, and much of South America which are relative newcomers to industrial-scale mariculture, the ongoing lack of institutional, financial, and infrastructure support for production development and expansion is likely to keep mariculture production relatively low on a global scale for the time being. Globally, some coastal provinces are currently sustaining an annual average production in the millions of tonnes, and many more are sustaining production in the hundreds of thousands of tonnes annually. The environmental and social effects of the historical geographic and production-based expansion of mariculture along a given section of coastline will, however, depend on the characteristics of the different farming activities as well as a number of environmental and social factors which are outside of the scope of this study.

Chapter 3

Aquaculture's Global Impact in the Decades Ahead: Mariculture Development Scenarios

3.1 Introduction

Seafood consumption continues to rise worldwide while the global catch of marine fisheries has been in decline since the late 1980s (Watson and Pauly 2001; FAO 2010c). This increasing trend of seafood consumption is possible primarily because of aquaculture's considerable global growth since 1970 (Brugère and Ridler 2004; FAO 2010c); this sector has been the fastest growing animal food production industry worldwide since 1970 (FAO 2010c). However, this capacity for rapid growth in the face of declining fisheries catches is associated with significant controversy. While proponents highlight aquaculture's social and economic benefits and promote this sector's rapid expansion as a "Blue Revolution", i.e., a solution for increasing global seafood supplies and thereby improving human well-being, much like the agricultural revolution of the mid-20^{th} century (Loder 2003), critics highlight the absence of effective policy and regulation for governing the sector, particularly with respect to the rapidly developing mariculture subsector. As in aquaculture, mariculture, or the cultivation, management and harvest of privately-owned aquatic organisms in marine and brackish environments (FAO 2008a; Chapter 2), is a resource exploitation activity with well-documented negative social and environmental tradeoffs to production (Pullin *et al.* 1993; Wu 1995; Naylor *et al.* 1998; 2000; Pauly *et al.* 2002; Delgado *et al.* 2003; Primavera 2006; Pullin *et al.* 2007; Goldburg 2008; Liu and Sumaila 2010).

As an awareness of our global ecological footprint grows, so too has widespread public support for improving the ecological accountability, or sustainability, of agribusiness practices (Jansen and Vellema 2004). Worldwide, mariculture is experiencing similar trends (Lebel *et al.* 2002; FAO 2010c). However, the path towards more 'sustainable development', broadly defined in *Our Common Future* as "Meet[ing] the needs of the present without compromising the ability of future generations to meet their own needs" (WCED 1987) is uncertain in both its trajectory and its consequences. Only a handful of strategic analyses exist to explore the 'big picture' of worldwide aquaculture production in the coming decades. No global analyses specifically explore the growing role of mariculture in future aquaculture supplies and how production may be affected as principles of sustainable development become more accepted in management policies worldwide. This lack of information for decision-making presents an additional challenge to policy-makers who, in addition to addressing more immediate stakeholder concerns such as food and livelihood security, are increasingly faced with the dual objectives of maintaining economic growth while upholding internationally recognized commitments to sustainable development.

Using a scenario-based approach to analysis, this paper constructs and explores four unique possible development futures for commercial mariculture in the next decades, in a world committed to either of four very different scenarios for global development. The overarching purpose of these scenarios is to explore the potential impact of a range of current individual and societal choices on the future of global aquaculture production, on people, and on the success of related global environmental governance and sustainable development targets (UNEP 2007). The conceptual framework for these scenarios is derived from the United Nations Global Environmental Outlook (GEO-4) (UNEP 2007). In this analysis, the modification of the GEO-4 methodology for mariculture is described, the outcomes presented, and the plausibility and some of the implications of these outcomes are discussed.

3.2 Materials and Methods

Scenarios are a tool for strategic policy analysis useful in identifying a range of options for action, their potential broader implications, and for reducing the uncertainties of decision-making for the future (Schnaars 1987; Godet and Roubelat 1996). They may be quantitative, qualitative, or a combination of both. Scenarios may represent multiple thematic or topical visions, and they are constructed using a variety of timeframes and methodologies that typically depend on the ultimate application of the outputs (Raskin 2005). First developed as a strategic planning tool for defence applications in the 1960s (Kahn and Wiener 1967), the growth of climate change concerns in the 1980s ushered in a new era of scenarios development for conservation planning and management (Leggett *et al.* 1992; Peterson *et al.* 2003).

The Global Environmental Outlook (GEO) "story and simulation" scenarios methodology represents a departure from more traditional predictive models, which contain almost exclusively quantitative, price-mediated drivers of change. These GEO scenarios incorporate less quantifiable, yet highly relevant, social and ecological drivers of change and overarching themes into their framework. This is accomplished by providing both quantitative and replicable assessments of possible futures as well as a range of reasoned storylines (UNEP 2002,2006; Ghosh 2007). As a result, these scenarios have the ability to more effectively highlight key drivers, uncertainties and assumptions about various futures as well as to more realistically identify the risks and benefits of different policy choices. The focus and robust design of the GEO-4 model, as well as its transparency, make the GEO-4 framework particularly appropriate for an analysis of the potential future impact of mariculture development on people and the environment.

3.2.1 The GEO-4 scenarios framework

The most comprehensive UN report on the environment and development to date, the GEO-4 or "Environment for development" assessment is a capacity-building process prepared by almost 400 experts across many disciplines and reviewed by over 1000 others (UNEP 2007). The four development scenarios (to 2050) created from this process are named so as to reflect the overarching theme driving decision-making in each. The description below of each scenario, highlighting their dominant thematic features, is adapted from UNEP (2007):

- ***Markets First:*** *The private sector, with active government support, considers maximized economic growth as the most effective path towards improved human and environmental well-being. The strength of markets is relied upon to convey these changes. When it comes to addressing environmental challenges, technological fixes are emphasised over time-tested, policy-based alternatives. With a focus on the sustainability of markets rather than human-environment systems, the priority in commercial fisheries is maximizing profits.*

- ***Policy First:*** *The government, with active private and civil support, uses a highly-centralized policy-based approach to balancing strong economic growth with minimized social and environmental impacts. Strong top-down policy interventions are aimed at overhauling environmental policy processes at all levels and promoting rapid progress towards key sustainable development targets. With a focus on the social and economic dimensions of development, the priority in fisheries is to find a balance between increasing profits as well as total catch and jobs.*

- ***Security First:*** *The government and private sector compete for control in efforts to maintain or improve the human well-being of society's rich and powerful. Reinforced silos of management as well as increased policy and expenditure on restricting the movement of people and trade seek to achieve sustainability in development only in the context of maximizing the access to and use of the environment by powerful actors. In fisheries, total catch is emphasized.*

- ***Sustainability First:*** *The government, civil society, and the private sector collaborate to equitably improve the environment and human well-being. Public-private partnerships are promoted as a way to ensure accountability, transparency, and legitimacy in strategic input for policy-making and implementation. Actors at all levels and across all sectors strive to overhaul environmental policy processes and to uphold international agreements put in place to address social and environmental concerns. There is a general acceptance of the long-term nature of tangible impacts in this regard. With equal weight given to environmental and socio-economic development policies, the focus in fisheries is on ecosystem restoration; however, emphasis is also given to increasing jobs and landings.*

These overarching development themes are shaped into narrative storylines using a series of five broad drivers (UNEP 2007), i.e. human-made or natural factors which, intentionally or otherwise, alter a system of interest in some way (UNEP 2006). These drivers are institutional and socio-political frameworks; demographics; economic demand, markets and trade; scientific and technological innovation; and value systems. Contained within each categorized driver of change are a series of critical social and economic uncertainties that ask questions about who is making decisions, what they are being made about, and how they are being made. In developing answers for these questions, a consistent set of assumptions for decision-making are drawn that differ for each scenario and therefore generate unique narrative outcomes (UNEP 2007). For the complete GEO-4 framework see Appendix to Chapter 3: Table B.1. While a stronger focus on environmental issues plays a thematic role in each scenario and its outcome, the term ‘development’ retains a broad range of economic, social, and environmental connotations in the GEO-4 process, as does the concept of ‘sustainability’.

A quantitative, model-based, component supports the narrative storylines. All models in the GEO-4 assessment use historical time series data standardized up to a common base year of 2000 (UNEP 2007). In the original GEO-4 assessment, a quantitative analysis of future global capture fisheries production trends was undertaken using peer-reviewed Ecopath with Ecosim models (Christensen and Pauly 1992; Walters *et al.* 1997; Pauly *et al.* 2000; UNEP 2007).

3.2.2 The GEO-4 framework: constructing mariculture narratives

The underlying framework of the original GEO-4 scenarios, i.e., the drivers, uncertainties, and fundamental assumptions, are either directly applied or are modified to create the new commercial mariculture scenarios in the year 2030, in analogy to the procedure for evaluating the future of capture fisheries in (Pauly *et al.* 2003). Here, we use these modified scenarios to explore how the future of the global mariculture industry might unfold along four development pathways, and relate the changes brought about by this development to the broader seafood market worldwide. Changes to the quantity, type, and geographic region of farmed species are explored in more detail within each scenario, as are some of the major costs and benefits of these changes on people and the environment. Appendix to Chapter 3: Table B.2 contains the complete framework and underlying rationales used in the development of the mariculture narratives.

Here, the assumptions and resulting narrative outcomes of the mariculture scenarios were developed and supported by the original GEO-4 framework, a synthesis of supporting literature, and expert opinion where available. Key sources used in the construction of mariculture scenario storylines include but were not limited to IFPRI’s *Fish to 2020* (Delgado *et al.* 2003), *Global aquaculture outlook in the next decades* (Brugère and Ridler 2004), *State of World Aquaculture 2006* (FAO 2006) and *The State of World Fisheries and Aquaculture* (FAO 2010c).

3.2.3 The GEO-4 framework: developing simulations of production

Simulations of future global mariculture production in 2020 and 2030 can strengthen and support the narrative storylines, as shown by both the Millennium Assessment and GEO-3 scenario process (Ghosh 2007). Also, linear regression models have been used by the FAO as a tool in demand forecasting to experimentally model historical time series of per caput fish consumption as a function of GDP (Ye 1999). These methods are not predictive, but rather intended as a means of visualizing how each development scenario storyline might influence, e.g., global mariculture production trends in the coming decades. Here, the simulations of mariculture production are modeled using segmented linear regressions with undefined breaks, constructed in R statistical software (RDCT 2008) (Figure 3.1). Segmented linear regression, a linear subset of segmented regression, has been previously applied to fisheries research by (Pauly *et al.* 2001a). Here, the model input data are global and country-level mariculture production statistics from 1950 to 2004 (see Chapter 2), compiled independently and supplemented with FAO FishStat Plus (v. 2.31) statistics (FAO 2008a), but excluding aquatic plants, and cyprinid and cichlid fishes.

The slope of the final linear regression segment (ending in 2004) was used to extrapolate a 'business-as-usual' (BAU) production trend line forward into the future. When assessing country-specific trends, if an historical time series contained fewer than 15 years of data, a simple linear regression was used instead of a segmented linear regression. In the few cases where the initial model outputs of extrapolated future trends were not deemed representative of the historical production trends, the production estimates for 2004 were projected into the future and served as the BAU projection.

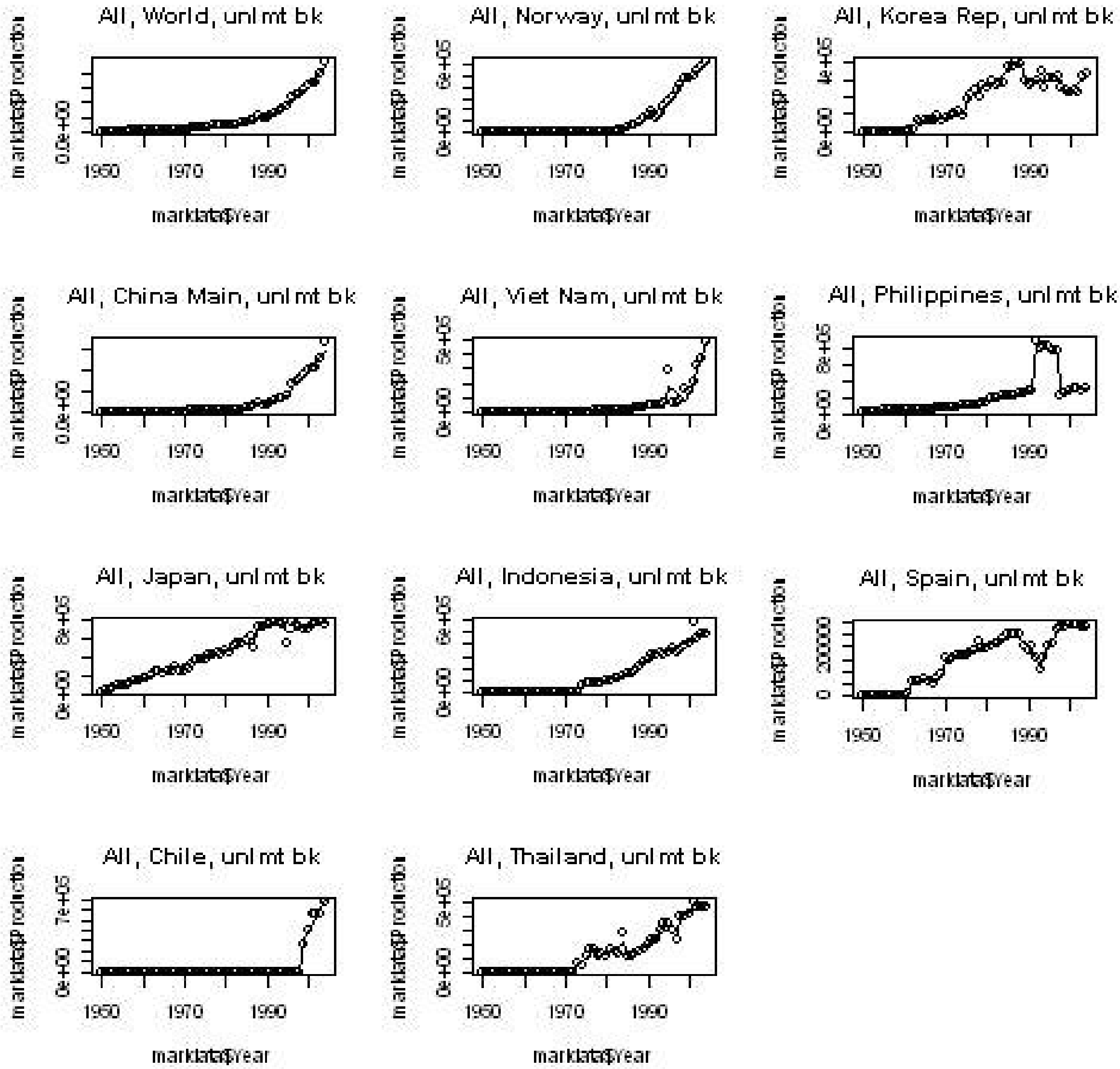

Figure 3.1: Segmented regression outputs generated by R, for the historical production of each analysed country. Future extrapolations of Business-as-usual production from the baseline year 2004 were determined by the slope provided by the last segment of a line in the unlimited breaks regression model.

The slope of the BAU production trend in 2004 was then used as a baseline for estimated future mariculture production trends under each scenario. An assumed deviation from the baseline was then selected for each scenario, based on scenario framework assumptions, in analogy to the procedure used in UNEP (2007) for the Marine Trophic Index (MTI) and capture fisheries (Table 3.1). Once the extrapolations of future production were generated for each scenario to 2030, the overall changes in the composition and production trends of major seafood commodity categories, and therefore the overall sustainability of the sector, were inferred beyond 2004. These increases or decreases from the baseline were determined based on the level of ecological consideration assumed in the underlying scenarios and the relative change in the average sector Mariculture Sustainability Index (Trujillo 2007). The MSI ranges from 1 to 10 (where 1 is low sustainability and 10 is high), and is based on 13 social and ecological indicators (Trujillo 2007). This exercise was repeated in more detail for the top three mariculture-producing countries.

Table 3.1: Estimated future annual rates of growth for mariculture production under each scenario, expressed as deviation from the Business-as-Usual baseline.

Scenario	**Scenario framework assumptions**	**Assumed deviation from BAU**
Markets First	Future global market drivers are capable of removing many of the current economic (and some ecological) constraints to further mariculture sector growth and expansion through technological innovation	+10%
Policy First	A positive global view of increasing mariculture sector development and production is slowed somewhat by renewed policy commitments to environmental sustainability considerations.	+5%
Business-as-usual	All factors of production held constant as of 2004.	--
Security First	The dominant interests of a rich minority and strong controls over the movement of people, trade, and technology transfer and information constrain further global sector development, expansion, and trade.	-5%
Sustainability First	A strong global recommitment to following through on multilateral environmental commitments to responsible mariculture development increases production constraints and decreases the demand for environmentally unsustainably seafood	-10%

3.3 Results: Development Scenarios of Global Mariculture Production in 2030

3.3.1 Markets first

In a *Markets First* world in 2030, key private sector actors, with active government support, are focused on improving the well-being of people and the environment through maximized economic growth and efficiency in the mariculture sector (UNEP 2007). This emphasis on economic drivers of development has led to an increased liberalization, strengthening, and expansion of existing international and regional trade agreements as well as the generation of new agreements, particularly in Asia (UNEP 2007). This improved global economic cooperation strengthens the trading of seafood, primarily within Asia but also between Asia and the rest of the world. Western markets for luxury seafood species such as salmon and prawns retain a driving role in the focus of global mariculture development (FAO 2006); however, by 2030 the growing and urbanizing Indian and Chinese middle classes have become a driving force for increases in both total and per caput global demand for diversified and high-value marine seafood products (Delgado *et al.* 2003; FAO 2009c). Despite this trend, seafood markets remain dictated by traditional supply and demand economics with few government controls (UNEP 2007) and the bulk of economic and social benefits derived from the production of high-value marine and brackish products still flows predominantly from poorer to richer countries and private entities (Kent 1997; Delgado *et al.* 2003).

By 2030, increased global economic liberalism has amplified the control over production and profits from fewer and larger multinational corporations (Frazer 2004; Anon 2006), capable of out-competing smaller-scale domestic farms through economies of scale. In this regard, many smaller, dispersed, and local farms have found themselves unable to keep up with the rising costs of production inputs; these include the increasingly erratic market price for feeds sourced from reduction fisheries that continue to be exploited beyond sustainable levels, as well as for feed substitutes (Rana *et al.* 2009). In some countries, smaller commercial mariculture operations are retained only by clustering firms together or by specializing production into one or two key species (or life stages) of high-value (Tveteras 2003), on producing high-value niche market products such as live trade species for the restaurant industry China, or on value-added operations.

As global population and incomes continues to grow the demand for and supply of high-value carnivorous marine species continue to increase globally. The widespread removal of trade barriers and technological constraints to increased production characteristic of *Markets First* increases overall mariculture production more than the other scenarios. However, the social priority of this scenario is on increasing profit rather than improving the availability and accessibility of seafood for people (UNEP 2007). In order to increase the profitability of mariculture, companies worldwide have focused their efforts on improving operational and cost efficiencies through the use of technological rather than policy-based solutions; indeed, most social, economic, and environmental challenges are addressed this way (UNEP 2007).

In this regard, many private companies and national governments have recognized that sustaining mariculture's high global rate of production and profits means sustaining the availability and accessibility of ecological inputs such as wild-sourced feeds, juveniles, suitable rearing sites, and water. By 2030, development research and technology has therefore focused strongly on the reduction and efficient use of these resource inputs by increasing the use of selective breeding practices and genetics, and alternative feed technologies. Farming practices worldwide have also become more intensive (Pillay 2004). In order to maximize marketability, it is common for companies to self-impose strict operational guidelines which ensure that their intensively-farmed seafood products are of high quality and readily meet a range of international market health and safety standards.

In some countries, addressing the technological constraints to increased mariculture production means exploring alternate, underexploited wild feed sources. These feed sources include krill and insect meals (Naylor *et al.* 2009; Murias 2010), as well as farmed low-value freshwater and brackish species destined for reduction into fishmeals and oils or for the direct feeding of penned high-value species such as tuna (FitzGerald Jr. 2004). In other countries, production constraints such as site availability, pollution concerns, and coastal resource-use conflicts are most efficiently circumvented by developing and expanding intensive offshore mariculture operations (Hopkins *et al.* 1997). This practice has the added benefit of escaping the few formal environmental protection measures implemented from previous decades (UNEP 2007). China, still the world's mariculture powerhouse in 2030, continues to struggle with consistently meeting international market standards for quality and safety. Aquaculture research and development are no longer under the exclusive control of the Chinese government and private feed and chemical companies invest significantly in Chinese mariculture extension activities. Disease prevention and control is therefore still widely addressed through the use of ecologically detrimental chemicals; however, the country makes notable advances in feed conversion and composition technologies (Hishamunda and Subasinghe 2003).

The worldwide increase in the use of technologies and practices promoting 'efficiency' under *Markets First* relates predominantly to the sustainability of seafood markets rather than the strengthening of ecological considerations in mariculture development and expansion (UNEP 2007). Despite this, a growing shift in the social values of Western seafood consumers has increased the intensity with which the ecologically-unsavoury aspects of irresponsible mariculture production are scrutinized (Lebel *et al.* 2002). Many producers worldwide have responded to a growing demand for more socially and environmentally ethical seafood products by developing niche markets for organically-produced or integrated multi-trophic (IMTA) species at a higher price premium (Jansen and Vellema 2004). In North America and Europe there is a strong private investment in the development of regionally or internationally-recognized eco-labeling and certification schemes (Bergleiter *et al.* 2009); however, the objectives of these schemes still favour economic, rather than ecological objectives.

3.3.2 Policy first

Under a *Policy First* scenario in 2030, government institutions worldwide, with active private and civil society support, make efforts to resolve many of the issues facing humanity and the environment through top-down, policy-based reforms (UNEP 2007). While economic growth remains a focal point for global mariculture development, it is acknowledged that such growth cannot be sustained without a stronger consideration of the negative social and environmental impacts that can accompany development.

However, in practice, most reform initiatives focus first and foremost on social considerations such as jobs and total production (UNEP 2007).

Specific governance actions are not carried out equally across and within regions internationally, but a certain homogeneity in efforts is created worldwide (UNEP 2007). This is a result of improved resource sharing and a better alignment among social and political institutions as well as a political cohesion with international agreements such as the Food and Agricultural Organization (FAO) of the United Nations' *Code of Conduct for Responsible Fishing*. Policy reforms for mariculture are led by national governments and international institutions, including the FAO. However, the slow pace of institutional reform and the inflexibility of a more centralized approach to implementing change means that few major reforms to the mariculture industry are widely implemented by 2030 (Lake 1994; UNEP 2007).

In spite of this slow rate of global policy change, two major initiatives relevant to aquaculture do emerge by 2030: The Aquaculture Stewardship Council (ASC) and global, FAO-driven reforms of aquaculture information systems. Created to complement the certification efforts of the Marine Stewardship Council (MSC) for responsible fisheries (WWF 2009), this Council, like the MSC (Jacquet *et al.* 2010), is not without its critics. However, by 2030 the ASC has achieved some success in initiating a widely recognized standard of environmental sustainability performance for the aquaculture practices for many of the most intensively farmed taxa worldwide such as penaeid shrimp, Atlantic salmon (*Salmo salar*), cobia (*Rachycentron canadum*), and marine bivalves (WWF 2009). For those producers able to afford such certification, this 'eco-labelling' also provides an additional market advantage (Bergleiter *et al.* 2009).

As of the beginning of the 21st Century, the FAO leads a strong international campaign to improve global information systems on the status and trends of aquaculture production worldwide, with an emphasis on China (FAO 2008d; Zhijie *et al*. 2008). This successful campaign leads to a more widespread recognition and understanding of the importance of quality aquaculture data, consistent and standardized reporting protocols, and better overall participation in information systems for effective global conservation and sustainability governance. The resulting collaborative effort at all institutional levels noticeably improves the organization and effectiveness of ecologically and socially sustainable management and governance frameworks in the aquaculture practices of many countries. Following its first National Census in 2006 (FAO 2009c), China continues to address the logistical challenges of improving the quality of its production statistics and implements further downward revisions to its production data (Rana *et al.* 1998; Zhijie *et al.* 2008). This downward revision to China's production data, combined with the increase in the effectivness of ecological and social governance and management in some of mariculture's less sustainable industrial-scale operations worldwide, contribute to a slight decrease in the global rate of mariculture production growth.

Widespread data improvements increase the total diversity of farmed species reported as produced globally due to the disaggregation of species from broader production categories (Chapter 2). Other impacts include revisions to previously under-estimated mariculture production factors such as the contribution of women to the farming, harvesting, and processing segments of the industry (FAO 2006) and the removal of wild-caught post-larvae/juveniles and/or breeders, such as often occurs for farmed shrimp and grouper species (Ahmed and Troell 2010). In response to this new knowledge, efforts have been made by some countries to curtail removals and to promote more benign alternatives. However, some developing countries still allow this collection of post-larvae and juveniles as they did in previous decades, if mainly to provide employment and incomes (Ahmed and Troell 2010).

As a growing global human population and rising incomes continue to increase the demand for wild-caught fish, and fishing pressure continues to increase (Pauly 1990; Delgado *et al.* 2003; FAO 2009c), the price of wild-sourced mariculture production inputs such as feeds and juveniles also continues to rise. For many countries, particularly in Southeast Asia, this is a major limiting factor to increasing the production, through mariculture, of highly sought-after marine and brackish species (Tacon 1997; FAO 2009c). This price increase is further exacerbated by reductions of perverse subsidies to fisheries, particularly fuel subsidies (UNEP 2007). Widespread moratoria on the production of genetically modified seafood, while assuaging the ethical and environmental concerns of primarily Western consumers (Nielsen *et al.* 2003), limit the options of many countries seeking relief from 'feed and seed'- limited production constraints. In many countries, the focus of production has therefore shifted out of necessity from carnivorous species to the lower-input production of more local omnivorous and herbivorous species with less complicated early rearing stages (Tacon 1997; Pullin *et al.* 2007), more intensive production with lower per-unit costs (at least in areas where fuel and water costs are not excessive and disease is not a major problem), or to freshwater aquaculture production.

The development of Integrated Multi-trophic Aquaculture receives considerable funding and attention because of its reduced potential for generating negative environmental impacts, for its ability to sustain a reasonable supply and diversity of food fish production outputs, and for its high degree of social acceptability (Chopin *et al.* 2001). However, the development and expansion of this system does not fully compensate for rising costs, a growing lack of suitable area for expansion, China's downward revision of its mariculture production figures, increases in the effective regulation of socially and environmentally unsustainable mariculture operations in some countries, and decreases in demand from Western consumers concerned about the sustainability of mariculture practices and the quality and safety of the fish produced (FAO 2009c). As a result, the global rate of mariculture production growth in this scenario becomes similar to the 6.1% annual growth rate in aquaculture production observable between 2004 and 2006 (FAO 2009c).

3.3.3 Security first

In a world where security comes first, the benefits of mariculture production and development are available only to a privileged few (UNEP 2007). By 2030, to better control and monitor the movement of people, goods, and services within and across their respective borders, governments around the world, with support from powerful private actors, have implemented stronger restrictions on migration and trade. Often these actions are influenced by ongoing political and physical conflicts fed by the socio-political interests of governments and private entities, as well as from the struggle to control increasingly scarce natural resources. As countries around the world adopt increasingly protectionist measures, the human population continues to grow within the confines of national borders (UNEP 2007).

The internal security focus of many government policies has lead to a reduction in international cooperation and trade by 2030. Both Official Development Assistance for aquaculture extension activities and international trade in seafood are reduced and what remains is strongly conditional on the interests of powerful governments, multinational corporations, and other powerful private interests (UNEP 2007). There is a growing distrust in the role and effectiveness of the United Nations and their specialized organizations such as the FAO. The role of the FAO is increasingly marginalized; as a result its global influence in supporting and promoting aquaculture research, development, the dissemination of information, and ecologically-responsible production, declines. The World Trade Organization (WTO) becomes a leverage tool to gain more political and economic control (Smith 2006; Lynn 2010). As has occurred in capture fisheries (Alder and Watson 2007), countries unable to gain sufficient political and economic autonomy are strong-armed into expanding and intensifying mariculture production for export to economically-developed foreign nations. The revenue from exported sales is brokered by, and primarily returned to, the coffers of government and private actors; the social benefits of mariculture production for poor and rural communities are marginalized

In response, countries and regions able to generate a production surplus of desirable seafood products have hoarded supply so as to increase control over their own economies and resources. Social value systems prioritize the maximization of seafood production (UNEP 2007); however, this hoarding is less about providing food to those in need than it is about gaining control over limited resources. China, a major global player in mariculture sector foreign trade (Pan 2005), increases its global political and economic bargaining power with the US and the EU and secures its dominance in global seafood markets. Conversely, for many countries and regions with a developing commercial mariculture sector, the widespread contraction of support, cooperation, and trade effectively terminates further research and development efforts. With widespread civil unrest on the rise coupled with a strong dependence on development assistance, attempts to further expand industrial mariculture in Sub-Saharan Africa are, by 2030, completely shelved for the foreseeable future.

The strengthened controls over formal markets and trade have lead to widespread growth in underground (i.e. informal) economies (UNEP 2007). Although unconfirmed due to widespread breakdowns in global information-sharing and cooperation, the unreported subsistence farming and small-scale domestic trade of lower-value mariculture species produced in brackish coastal zones throughout food-deficit countries in Asia and Latin America is thought to have increased dramatically. The environmental effects of this unreported production are poorly documented and poorly addressed. Pollution and disease outbreaks from poorly sited and poorly managed farming operations remain a widespread problem (Delgado *et al.* 2003) and increase in many regions as mariculture production continues to expand and intensify.

The human pressure on world oceans increases dramatically. Fish catches continue to increase but the quality of catch decreases (UNEP 2007) and fisheries race further and further down marine food webs (Pauly *et al.* 1998). This has placed an even greater pressure on aquaculture to fill the increasing gap between seafood supply and demand. In the face of major oceanic biodiversity decline, especially the widespread depletion and disappearance of large and long-lived, high-value predatory marine species due to overharvesting (Naylor and Burke 2005), governments and private companies proclaim the necessity of 'genetic resource protection' to the public (UNEP 2007). Considerable funds for research and development are invested in increasing the total global yield of farmed marine finfish species such as tuna (*Thunnus* spp.), Atlantic cod (*Gadus morhua)*, flatfishes (Pleuronectidae and Paralichthyidae), sea bass and breams, snappers (Lutjanidae), and salmon (*Oncorhynchus* and *Salmo* spp.).

The increased global production of these carnivorous species has further adverse effects on global fisheries. Technology-based advances for reducing the fishmeal component in feeds and improving feed conversion ratios are closely guarded and not widely traded; as a result, more of the global fisheries catch is being diverted to reduction fisheries for fishmeals and oils used in high-value carnivorous fish feeds.

An expanded Antarctic Ocean krill fishery supports much of this increase (Nicol and Foster 2003). This change in the composition of reduction fisheries, accompanied by an increase in global fishmeal prices from increasingly over-exploited capture resources, is further driven by the actions of countries with major reduction fisheries such as Peru, who seek to increase their domestic security of supply and reestablish strong markets for the human consumption of small pelagic fish such as Peruvian anchoveta (*Engraulis ringens*) (Pauly 2006; Alder and Watson 2007; Alder *et al.* 2008).

Although mariculture practices have expanded both offshore, coastally, and on land worldwide by 2030 and total global production continues to increase, the global rate of mariculture production growth has decreased under *Security First*. Increases in feed prices, restrictions on international trade and cooperation, resource use conflicts, the rising price of increasingly exploited natural resources (energy, water), increasing ecosystem impacts, limited development assistance, and closely guarded innovations to production technology have all contributed to this decline.

3.3.4 Sustainability first

In a *Sustainability First* world in 2030, all government, private, and civil sector actors across all institutional levels are following through on their individual and collaborative commitments to address the most pressing social and environmental sustainability issues (UNEP 2007). Over the past 20 years, a growing social movement has begun to effectively advocate for a more balanced and equitable treatment of social, economic, and environmental issues in development policies. In response, by 2030 both national and international institutions have collaboratively begun to rework their institutional and trade governance mandates to incorporate more than drivers of economic growth and efficiency (UNEP 2007). This new approach to governance increases the global focus on ecosystem restoration, includes a stronger emphasis on decision-making inputs from the private sector and civil society, and results in significant improvements to general cooperation and compliance in resource use issues worldwide (UNEP 2007).

Globally, an increase in jobs and total production are socially valued in the fisheries and aquaculture sectors, but only if the underlying marine ecosystem is maintained and/or restored (UNEP 2007). Among wealthier major seafood consumers in the USA, Canada, and the EU, there is an increasing growth and diversification in the demand for more responsible, ecologically sustainable, and ethically-produced seafood products. This is a trend carried over and strengthened from previous decades (Lebel *et al.* 2002; Jansen and Vellema 2004). The EU, already a strong advocate for the sustainable certification of traded aquaculture products (Bergleiter *et al.* 2009), continues its trend as a global leader in many policy reforms in this regard. As a result, there has been a marked global increase in the occurrence of more community-based organic, polyculture, and integrated multi-trophic mariculture practices, as well as a rise in the use of closed containment and recirculated production technology for those countries able to afford the financial cost and the increase in energy use. The widespread use of these aquatic farming practices has mitigated many of the negative ecological impacts of mariculture on vulnerable coastal ecosystems (FAO 2006), and in some countries has managed to offset the rate of production decline experienced in the farming of typically less sustainable species like salmonids and seabreams (Blancheton 2000). Bowing to international pressure and with considerable development assistance, China has made great strides in reducing its use of chemicals and wild-sourced resources in production, and has scaled back production in some of its more ecologically-sensitive coastal habitats.

Mariculture producers worldwide are largely receptive to widespread reforms promoting ecological sustainability. One reason for this is that they must now comply with new and closely monitored environmental regulations to remain operational and competitive in international markets. It is also because they recognize that producing fish in a more economically, socially, and environmentally sustainable way makes long-term, sustainable business sense (Costa-Pierce 2003). In this regard, with strong support from civil society, private, and government sectors, the Aquaculture Stewardship Council and other sustainable certification schemes enjoy reasonable success in their efforts to foster responsible aquaculture production worldwide while providing a brand for increased marketability.

Although widespread efforts are made to open and to improve fair trade in international markets, the net flow of seafood and its economic benefits from poor to rich countries (Kent 1997), and the inequalities of global food distribution, remain in 2030 (UNEP 2007). Regardless of market reform efforts, the world population, the subsequent demand for food fish, and the pressure on the world oceans, increases. Despite a rise in consumer awareness and a large-scale shift in social values, the luxury market demand for carnivorous, high-value, and highly desirable farmed marine and brackish species such as shrimp and prawn, remains (Delgado *et al.* 2003).

To mitigate some of the negative social and environmental effects often generated by the production of these high-value species, many governments and private entities have allocated greater and more widespread resources for job skills training and other educational programs, for socially and environmentally-conscious marketing, research and development innovations, and for the promotion of open-source technology transfer and diffusion (UNEP 2007). The job training and education initiatives greatly improve the job and wage status of many employed by the mariculture sector, provide alternative livelihood options (where available), and impress upon the broader labour force the long-term value of ecologically responsible farming practices. These education initiatives also target consumers and improve a general awareness of how farmed seafood is sourced and how to purchase in a more socially and ecologically-conscious manner. The widely shared technological innovations improve the efficiency of feed and energy use in production, artificial breeding, and rearing technologies as well as improve post-harvest procesing to maximize seafood product value in many developing countries that would not otherwise have the resources to innovate. As a result, a greater breadth of marine ecosystems worldwide benefit from widespread reductions in the use of wild-sourced feed and seed material, as well as on natural resource inputs such as fuel and water.

Market innovations generated by a range of actors continue to develop a viable Western market for semi-intensively-produced omnivorous and herbivorous finfish species with globally-established production, such as milkfish, mullet, carp, and tilapia. These efforts lead to a slight global increase in the diversification, production, and international trade of lower-value brackish species. Expanding on grassroots efforts to increase a sense of community responsibility (CBC 2010), some regions witness the emergence or revitalization of community-supported mariculture co-ops for desirable species such as shellfish, and brackish pond and lagoon-reared shrimp, crab, and finfish, which are produced in farms operating on a smaller scale (Goswami and Sathiadhas 2000; Duffey 2003).

Despite increases in the production of some species, particularly bivalves, and an increase in the total quantity of farmed seafood produced globally since 2004, the global rate of mariculture production has decreased considerably. Much of this decrease is driven by rates of production decrease in China. The widespread increase in effective regulatory constraints aimed at reducing ecological impacts and promoting ecosystem restoration has meant that many mariculture operations have had to scale back their production practices, reduce the production of species dependent on carnivorous feeds (e.g., salmon), and slow development expansion. In addition, a shift in values, primarily in developed countries, has led to a lowered consumption of animal proteins (UNEP 2007) and thus reduced overall per capita global demand for mariculture products.

3.3.5 Simulations of mariculture production

Global trends

If Business-as-Usual rates of production continue from the 2004 baseline year (holding all else constant), approximately 50 million tonnes of marine and brackish species could be produced worldwide in 2020 (Figure 3.2). This BAU projection, which could supply an additional 32 million tonnes of mariculture production above the 2004 baseline, implies an annual production increase of 1.66 million tonnes. If these same trends extend for another decade, by 2030 the quantity of mariculture products worldwide could reach 67 million tonnes. If the proportion of freshwater aquaculture that contributes to global aquaculture production remains similar to that reported by the FAO in 2004-2006, freshwater and mariculture production combined could achieve a total production of 130 million tonnes of fish in 2020, i.e., an additional 90 million tonnes greater than the 2004 baseline. By 2030, with these same proportions, aquaculture could be producing 172 million tonnes annually worldwide. When this baseline simulation of mariculture production is compared to production simulations under the lowest growth rate scenario (*Sustainability First*) and the highest growth rate scenario (*Markets First*), the total difference in global mariculture tonnage in 2020 is ±2.7 million tonnes from the BAU baseline. In 2030, this difference increases to ±4.3 million tonnes from the BAU baseline.

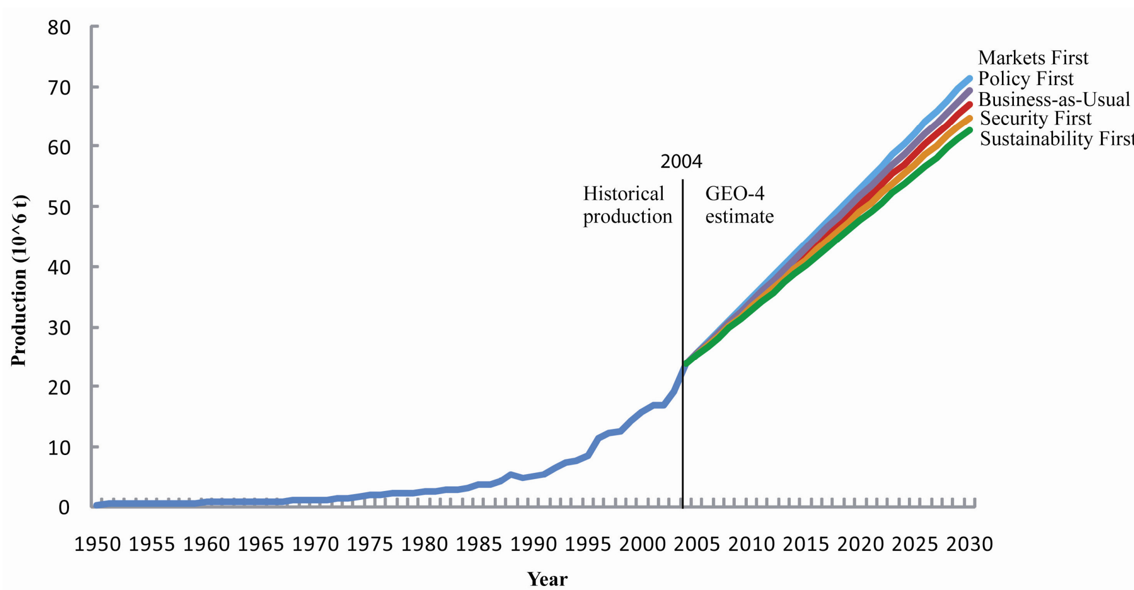

Figure 3.2: Extrapolation of future global mariculture production trends, based on historical trends. Represented is a business-as-usual scenario, with all rate-changing factors held constant from 2004 forward, and each GEO-4 scenario, with production growth increased by the increments described in Table 3.2. Source: GMPD (Chapter 2).

When this simulated mariculture production is combined with both the FAO estimate of freshwater production from 2006, assumed to experience similar growth, and with the results from the GEO-4 simulations of future marine fisheries landings (UNEP 2007), total global fisheries production estimates in 2020 range between 248 million tonnes under the *Sustainability First* scenario and 272 million tonnes under *Markets First*. By 2030, simulated production ranges between 281 and 317 million tonnes of seafood.

Table 3.2 compares the supply-based scenario trends of estimated total aquaculture production derived in the mariculture simulations (GEO-4 Mari) to global consumption demand-based estimates of production generated by the International Food Policy Research Institute's (IFPRI) *Fish to 2020* project (Delgado *et* *al.* 2003), and in the forecast models of (Ye 1999), (Wijkstrom 2003), and (Brugère and Ridler 2004). All estimates assume stagnation in fisheries catches. Wijkstrom's analysis provides an intermediate estimate of consumption demand for aquaculture of 59.7 million tonnes in 2010 (Wijkstrom 2003; Brugère and Ridler 2004), or an estimated 8.6 kg per capita.

Table 3.2: Simulations of future global and per capita aquaculture production in million tonnes. 'All aquaculture' production in GEO-4 Mari is inferred from the mariculture simulations and FAO aquaculture production proportions from 2006 (FAO 2009c). Actual global production reported by FAO (excluding seaweeds) is presented for the baseline year of 2004 (FAO 2009c). Adapted from Ye (1999); Delgado et al. (2003); Wijkstrom (2003) and Brugère and Ridler (2004).

Business-as-Usual

Year	**2004**	**2020**		**2030**	
Model	**FAO**	**GEO-4 Mari**	**IFPRI**	**GEO-4 Mari**	
All aquaculture (10^6t)	**45.9**	125.0	68.6*	167.8	--
from mariculture	**19.6**	48.6		65.2	--
of which China	**12.1**	33.4	35.0	45.0	--
Global per capita (kg)	**7.0**	16.3	6.9	20.2	--

Highest

Year	**2004**	**2020**		**2030**	
Model		**GEO-4 Mari**	**IFPRI**	**GEO-4 Mari**	**Ye**
All aquaculture (10^6t)	--	137.4	83.6*	184.6	121.6*
from mariculture	--	53.4	--	71.7	--
of which China	--	36.7	55.2	49.5	--
Global per capita (kg)	--	17.9	10.4	22.2	14.6

Lowest

Year	**2004**	**2020**		**2030**	
Model		**GEO-4 Mari**	**IFPRI**	**GEO-4 Mari**	**Ye**
All aquaculture (10^6t)	--	112.5	46.6*	151.0	65.1*
from mariculture	--	43.7	--	58.7	--
of which China	--	30.0	30.8	40.5	--
Global per capita (kg)	--	14.7	6.1	18.2	7.8

*From analysis of Brugère and Ridler (2004)

The differences in the underlying drivers and assumptions of each explored mariculture future will affect both total global mariculture production and the global composition of species produced. Table 3.3 provides a generalization of likely future changes to global mariculture production trends by major IFPRI commodity group.

Table 3.3: Likely changes to mariculture production trends by 2030 under each scenario, by broad commodity category and relative to the 2004 baseline. A relative decrease in average MSI means lower overall sector sustainability and an increase means higher sustainability. Commodity categories are based on IFPRI's IMPACT model (Delgado *et al.* 2002).

Scenario	**Change in rate of production growth trends by major commodity group**		**Level of ecological consideration in decision-making (UNEP 2007)**	**Relative change in avg. sector MSI (Trujillo 2007)**
	Increase	**Decrease**		
Markets First	High-value finfish High-value crustaceans High-value other	Low-value finfish	Low	Decrease
Policy First	High-value finfish High-value crustaceans High-value other	Low-value finfish	Higher	Slight increase
Baseline	High-value finfish High-value crustaceans High-value other	Low-value finfish	Intermediate	No change
Security First	High-value finfish High-value crustaceans Low-value finfish	High-value other	Lower	Slight decrease
Sustainability First	High-value other Low-value finfish	High-value finfish High-value crustaceans	High	Increase

High-value finfish includes: *Tunas, salmonids, cod, flatfishes, basses, breams, groupers*
High-value crustaceans includes: *Prawns, crabs, lobsters, misc. marine crustaceans*
High-value other includes: *Mussels, oysters, scallops, clams, cockles, abalones, misc. marine mollusc*
Low-value finfish includes: *Freshwater fish*, misc. marine fishes, eel, mullets, milkfish, barramundi*

Country trends

At the country level, production responses under each scenario will differ from overall global trends depending on the particular issues relevant to that country's mariculture sector (i.e., adequate feed and seed supplies, quality and availability of technology and training, suitable land and water resources, availability and accessibility of markets, institutional and political support etc.). However, the overarching thematic drivers and assumptions of the global mariculture scenarios remain relevant at the country scale - a market-based focus on development in a given country, for example, is still likely to increase rates of future mariculture production more than any other scenario. Figure 3.3 conceptualizes how the underlying GEO-4 development scenario drivers could affect country-level production trends by 2020 and 2030 when the same global decision rules are applied to the national mariculture production trends of the top ten producing countries in 2004 (representing 90.6% of total mariculture production in 2004, excluding aquatic plants).

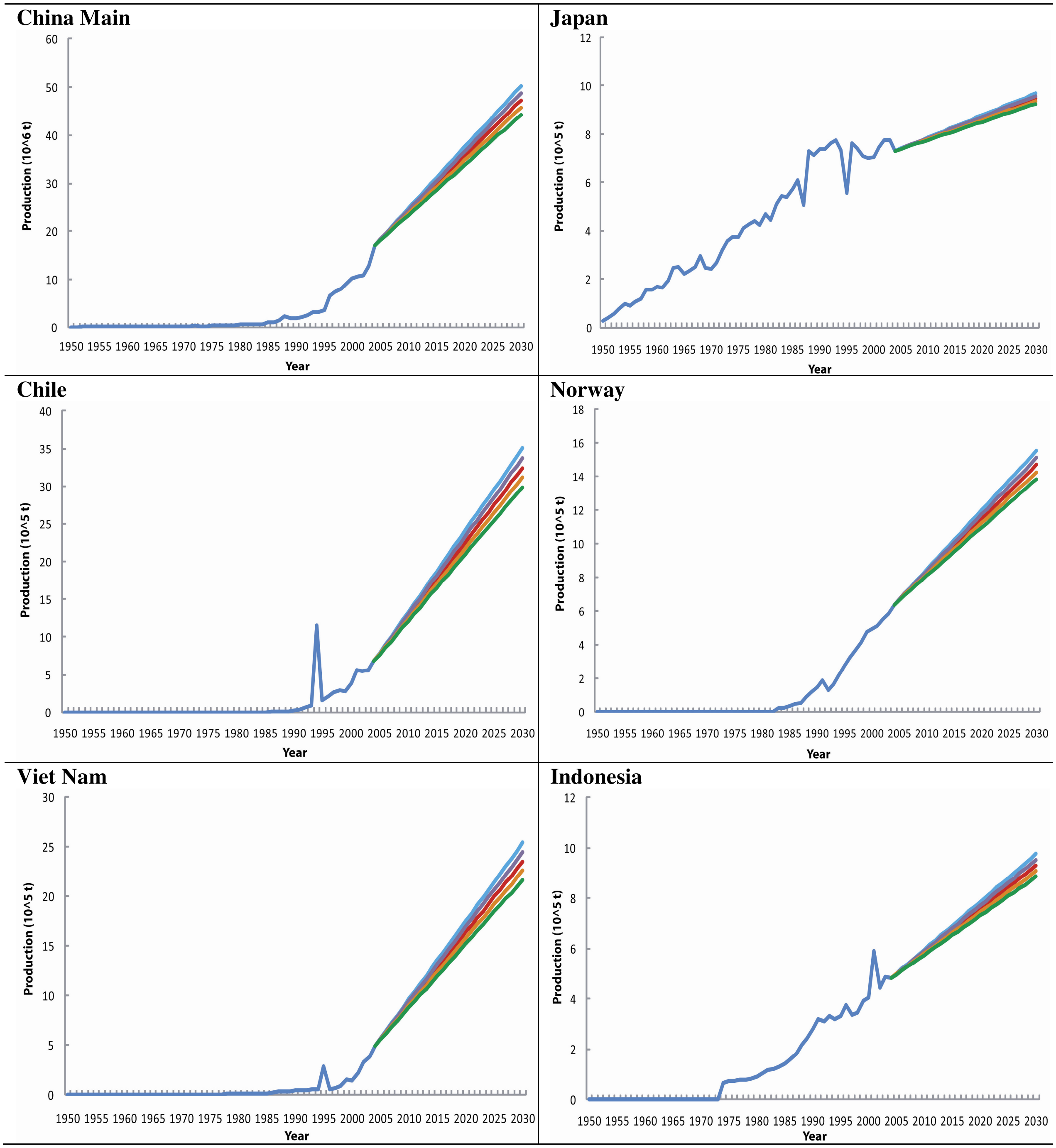

Figure 3.3: Total mariculture production in 2030 by top 10 producers in 2004. Production excludes aquatic plants, cichlids, and cyprinids. Historical production prior to 2005 is represented in dark blue (Chapter 2). Annual increment of production growth above Business-As-Usual baseline (Red): Markets First: +10% (in light blue); Policy First: +5% (purple); Security First: -5% (orange); Sustainability First: -10% (green). Figure continues on next page.

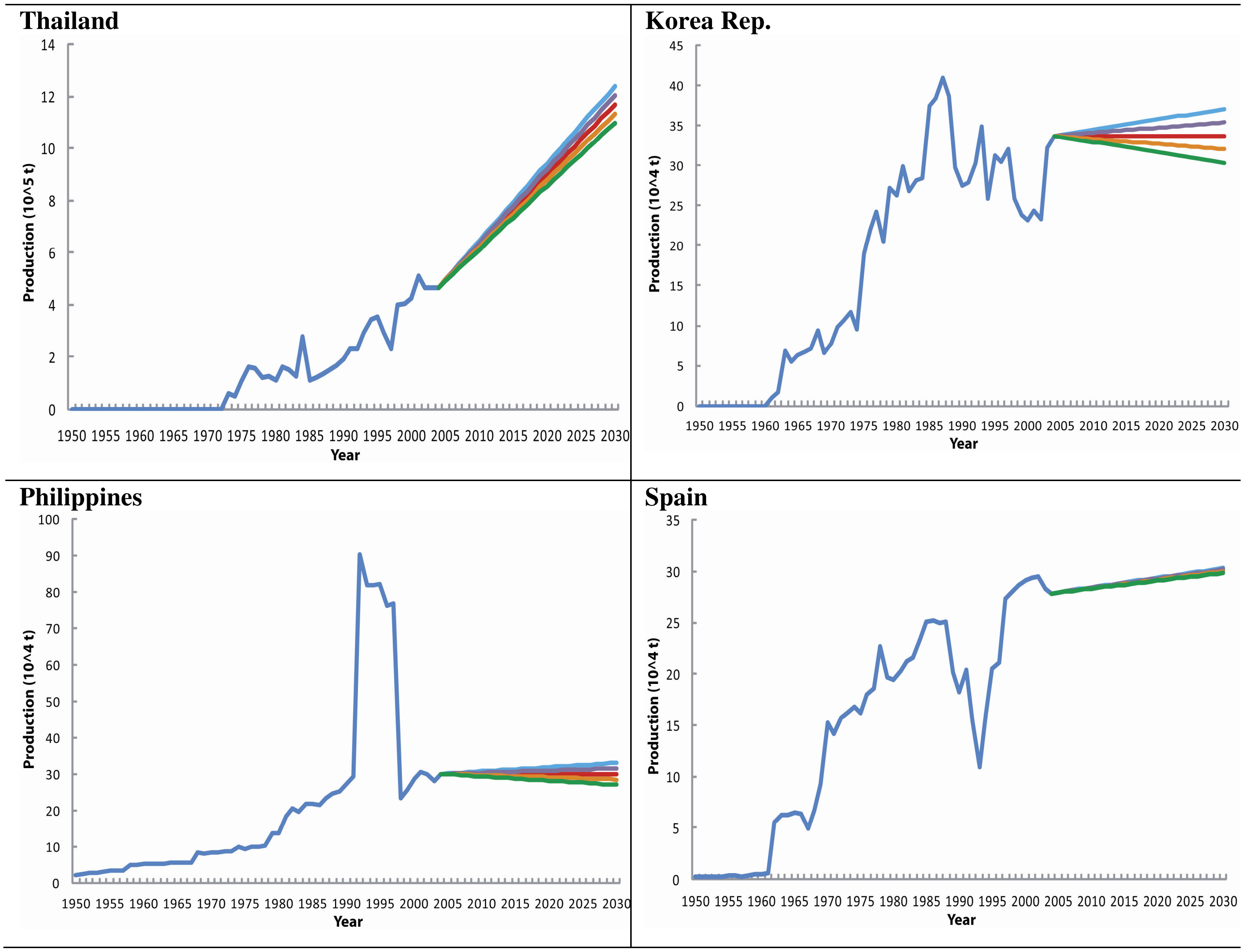

Figure 3.3 continued: Total mariculture production in 2030 by top 10 producers in 2004.

The quantity and diversity of taxa produced within a given country will also be affected by the strength of environmental considerations implemented into future development policy pathways. Table 3.4, Table 3.5 and Table 3.6 present proposed overarching changes to the production trends of the top species produced within each major IFPRI commodity category for the top 3 global mariculture producers in 2004 (representing 60% of global mariculture produced in 2004, and between 75% and 95% of each country's production). Species production responses in a given country may differ slightly from the commodity category trends of which they are a part in Table 3.3 due to country-specific differences in the indicator scores which contribute to a species' MSI ranking (See Methodology section and Trujillo 2007).

Table 3.4: Proposed change in top Chinese species production trends and their average MSI from 2004 baseline to 2030 in each scenario. The species below represent 76% of national mariculture production in 2004. Commodity categories are from IFPRI's IMPACT model (Delgado *et al*. 2002). The MSI for each species, in parentheses, is either direct or adapted from (Trujillo 2007), where 1 is low sustainability and 10 is high. The 'Baseline' scenario reflects true species production trends in 2004 (Chapter 2).

Scenario	**Change in growth rate of production trends by major commodity group**			**Avg. MSI**
	Increase	**Sustain**	**Decrease**	
Baseline	*Lateolobrax japonicus* (4.8) *Penaeus vannamei* (3.9) *Ruditapes philippinarum* (7.0)	Misc. Marine finfish (5.4) *Crassostrea gigas* (5.4) Marine Molluscs nei (5.3)		= 5.3
Markets First	*L. japonicus* *P. vannamei* *R. philippinarum / C. gigas*	Marine Molluscs nei	Misc. Marine finfish	< 5.3
Policy First	*L. japonicus* *R. philippinarum*	Misc. Marine finfish *C. gigas/* Marine Molluscs nei	*P. vannamei*	≥ 5.3
Security First	*L. japonicus* Misc. Marine finfish	*R. philippinarum / C.gigas* *P. vannamei*	Marine Molluscs nei	≤ 5.3
Sustainability First	*R. philippinarum*	*C. gigas* Marine Molluscs nei	*L. japonicus* *P. vannamei* Misc. Marine finfish	> 5.3

Table 3.5: Proposed change in top Japanese species production trends and their average MSI from 2004 baseline to 2030 in each scenario. The species below represent 84% of national mariculture production in 2004.

Scenario	**Change in growth rate of production trends by major commodity group**			**Avg. MSI**
	Increase	**Sustain**	**Decrease**	
Baseline		*Seriola quinqueradiata* (5.5) *Penaeus japonicus* (5.5) *Crassostrea gigas* (7.1) *Pecten yessoensis* (6.7)	Misc. Marine Finfish (5.4)	= 6.0
Markets First	*S. quinqueradiata* *P. japonicus* *C. gigas* *P. yessoensis*	Misc. Marine Finfish		= 6.0
Policy First	*C. gigas* *P. yessoensis*	*S. quinqueradiata* *P. japonicus*	Misc. Marine Finfish	≥ 6.0
Security First	*S. quinqueradiata* *P. japonicus* Misc. marine finfish	*C. gigas* *P. yessoensis*		≤ 6.0
Sustainability First	*C. gigas* *P.yessoensis*	*P. japonicus* Misc. marine finfish	*S. quinqueradiata*	> 6.0

Table 3.6: Proposed change in top Chilean species production trends and average MSI from 2004 baseline to 2030 in each scenario. The species below represent 95% of national mariculture production in 2004.				
Scenario	**Change in growth rate of production trends by major commodity group**			**Avg. MSI**
	Increase	**Sustain**	**Decrease**	
Baseline	*Salmo salar* (2.5) *Mytilus chilensis* (7.0)	*Oncorhynchus mykiss* (6.1)	*Oncorhynchus. kisutch* (2.8)	= 4.6
Markets First	*S.salar* *O. mykiss* *O. kisutch*	*M. chilensis*		< 4.6
Policy First	*M. chilensis*	*S. salar* *O. mykiss*	*O. kisutch*	≥ 4.6
Security First	*S.salar*	*O. mykiss* *M. chilensis*	*O. kisutch*	≤ 4.6
Sustainability First	*M. chilensis*		*S. salar* *O. mykiss / O. kisutch*	> 4.6

3.4 Discussion

3.4.1 Environmental and social implications of scenario outcomes

The previous three decades of rapid global mariculture expansion and growth (Chapter 2), the stagnant state of capture fisheries (FAO 2010c), and an intensive use of aquatic ecosystems suggest that the development choices made in the next decades will be crucial for the long-term sustainability of fisheries systems. Given projected population increases and the continued growth in per capita consumption of fish worldwide -- from an average of 11.5kg in the 1970s to 16.7 kg in 2006 (FAO 2009c), the FAO projects that aquaculture will need to produce an estimated 80.5 million tonnes, or an additional 28.8 million tonnes per year by 2030 to maintain current seafood demand and consumption rates, all else remaining constant (FAO 2008c). In meeting this target, the suite of development options available to us will have a wide range of social and ecological implications.

With regards to social implications, the model outputs from Delgado *et al.* (2003) have global food fish production increasing slightly faster than the global population to 2020 in the baseline scenario; aquaculture contributes 41% of this volume globally. However, aquaculture's projected role in meeting food fish production demand to 2030 is more uncertain. Ye's (1999) highest demand forecast scenario of aquaculture production easily meets the FAO's projected required increase by 2030; however, the author's lowest-producing scenario falls short of this goal. On the other hand, our results suggest that meeting projected demand in 2030 should be achievable under current (or even slightly decreased) rates of mariculture production growth, coupled with current rates of freshwater aquaculture growth and stagnant fisheries catches.

However, this result is highly conditional on a number of strong assumptions, including the nature of the relationship of mariculture to both freshwater aquaculture and fisheries. Both this analysis and the analysis of others (Delgado *et al.* 2003; Wijkstrom 2003; FAO 2009c) assume that growth in aquaculture, and not fisheries, will be the key to meeting the food fish demands of the future. These analyses also identify similar factors that will strongly affect future rates of global fish production. These include: the global price of fish, of fishmeal and oil used in animal feeds (including farmed carnivorous marine and brackish finfish and crustaceans), and of production; the capacity for widespread technological improvements to feed conversion ratios; the rate of aquaculture growth in China and the accuracy of its reported production; the rate of human population growth and food fish demand; the availability of suitable areas for expansion in freshwater, marine, and brackish environments; and the capacity of aquatic ecosystems to withstand increased stresses. And last but not least, these studies assume that fisheries catches can be both maintained at present levels, and supply a growing amount of inputs to the aquaculture sector (foremost fishmeals and oils), which is probably an unrealistic assumption in the light of continued debates about fisheries sustainability (Pauly *et al.* 2003; Worm *et al.* 2006; Jenkins *et al.* 2009; Worm *et al.* 2009).

The range in production between the highest and lowest-producing scenarios indicates little global variation in 2030. However, these global trends are likely to mask more significant changes at the country level, and countries will be favoured differently within each scenario. In this regard; a difference in production of a few hundred thousand tonnes and in the availability of certain fish and fish protein could have significant social and environmental ramifications for a given country. For example, while a *Sustainability First* future may increase the total global production of bivalves (in the place of higher trophic-level taxa with a lower MSI) and contribute to an increase in total global seafood tonnage, the actual availability of meat for consumption could be dramatically reduced because bivalve production is reported in shell weight (which may differ from meat weight by a factor of six for some species) (Ye 1999; Wijkstrom 2003). In addition, the lower comparative economic value of bivalves to finfish and crustaceans could mean that the overall profits derived from mariculture may decline in some countries even though production is increasing. Ultimately, this simulated variation highlights the uncertainty in dealing with the future, as well as the range of effects that individual and collective decisions can have on future global mariculture development.

Changes in global development strategies are certain to affect not only currently produced species, but those presently in experimental trial or small-scale production. That these species are not included in the scope of this exercise does not preclude their potential to play an influential role in the future direction of mariculture development and the overall sustainability of the industry. Indeed, many marine and brackish species currently being considered for further expansion in national development plans are high-value bivalve species such as abalone and oyster, crustacean species such as prawn and crab, and carnivorous finfish species such as salmon, cod, grouper, and flatfish (Brugère and Ridler 2004). Other species excluded from the scope of this exercise, in particular aquatic plants and farmed freshwater species like cichlids (e.g., tilapias of the genus *Oreochromis*) and cyprinids (e.g., the common carp *Cyprinus carpio*) are also likely to play a critical role in the future global outlook of food fish production for human consumption. These taxa comprise a major proportion of the fish produced and consumed globally in developing and food-deficit countries (Delgado *et al.* 2003; FAO 2009c), while aquatic plants comprise over 40% of all production (by weight) in marine and brackish environments (FAO 2006). It should be recognized, however, that in addition to positive impacts, the farming of such species can also have negative effects (Phillips 1990; Canonico *et al.* 2005; Liu *et al.* 2009).

Several current trends indicate a desire to move the development of aquaculture in a more environmentally-conscious direction. A recommitment to sustainability goals through major global and regional policy developments (UNCSD 2002; UN 2009a), the growth of consumer awareness campaigns (Jacquet and Pauly 2007), scientific insights (Naylor *et al.* 2000; Costa-Pierce 2003), and the popularization of farming practices with a smaller footprint (Ridler *et al.* 2007; FAO 2009c) are examples of just a few such trends. Other trends, however, tend in an opposite direction. Globally, situations of conflict, inequality, isolation, instability, and a desire to maintain the existing imbalances of power are evident in the widespread prioritization of funding and support for increased national security and military spending (UNEP 2007). Under such a global policy model, actions are driven by self-interest; as a result, many of the most pressing ecological and social concerns of the day persist. Ultimately, as we move deeper into the 21st Century, the dominant global fisheries production trends, and the role of ecologically and socially responsible mariculture development within these trends, are uncertain and will differ by region.

Refraining from an explicit quantification of the potential environmental effects of mariculture development in 2030, the four development scenarios highlight the depth and breadth of environmental tradeoffs possible under different development regimes. In a *Markets First* future, the focus on removing production constraints to mariculture creates a scenario where the absolute use of and pressure on environmental inputs is likely to increase the most out of any of the four global scenarios. This is because the total global volume of additional production is the highest, as is the rate of increase in the production of intensively-raised, high value and carnivorous finfish and crustacean species. Given what is known about the variety of environmental degradation that can occur under such a production focus (Naylor and Burke 2005; Primavera 2006), it is completely plausible to assume that the next twenty years of market-driven choices will exacerbate preexisting trends of coastal ecosystem degradation and further reduce the quality and availability of water and land resources for other coastal activities, particularly in developing countries with fewer social constraints to production growth (Pullin *et al.* 1993). When the possibility of such degradation is considered alongside other interlinked factors held as constant in this exercise (such as other resource use activities, climate change, and natural disasters), the future marine and coastal environmental outlook, and the capacity for sustained levels of high mariculture production growth, appears at considerable risk.

Conversely, the *Markets First* approach to development could provide the most effective and widespread opportunity to decrease the use of wild resources in mariculture production by dramatically improving the efficiency of ecological resource input use. In seeking to maximize economic benefits, some countries may find more value in promoting alternative coastal activities such as carbon sequestration, eco-tourism, and recreational fisheries and thus some heavily-used coastal resources could become unavailable for mariculture production. Instead of supplementing mariculture production with alternate activities, some countries may shift towards a more semi-intensive production system with fewer ecosystem inputs and a lower species MSI in order to both maintain high rates of mariculture production and profits and capitalize on the economic benefits of alternative activities.

In a *Policy First* future, a prioritization of more short-term socio-economic benefits to development and a top-down policy approach to addressing the ecological consequences of mariculture development means that environmental reforms are likely to occur slowly and yield only few tangible improvements to ecosystem health in the next two decades (UNEP 2007). This increase in future production above the baseline, particularly with respect to the production of high value carnivorous finfish and crustacean species, indicates that current trends of coastal resource exploitation are likely to continue into the future. However, the future dependence on wild-sourced production inputs is less clear in this scenario.

On one hand, the total global volume of mariculture produced by 2030 is not as great as in *Markets First*; accordingly, the global pressure placed on the marine and coastal environment is therefore also not likely to be as great. The improved aquaculture information systems can increase the effectiveness of the few environmental policy reforms that are implemented by 2030 (UNEP 2007; FAO 2008d), as well as promote alternative production choices that may sustain or minimally reduce rates of production while reducing environmental impacts. The social receptiveness to change through environmental policy reforms appears to have a stronger local variation in this scenario than in either of the more extreme development scenarios. The incorporation of more ecologically-considerate policies is more likely to be tied to the stability of a given country's past baseline production trends for a given species than in more market or ecologically-driven scenarios. On the other hand, this scenario reduces emphasis on the development, transfer, and trade of technological innovations (such as genetic modifications) designed to improve growth and rearing efficiencies and improved feed conversion technologies. This could mean that many of the current input inefficiencies of production may remain under-addressed despite a worldwide increase in mariculture production by 2030. As a result, the use of environmental inputs for production in the *Policy First* scenario may be the same as (or even greater than) in the *Markets First* scenario.

In a protectionist and nationalist *Security First* world, the emphasis on the security of development benefits for the rich and powerful means that sustaining or restoring the health of marine and coastal ecosystems is not a widespread priority. Indeed, a range of environmental resources become degraded in the model outputs of the original GEO-4 *Security First* future by 2030 (UNEP 2007). In a scenario that seeks to maximize total mariculture production, examples of degraded resources in marine and coastal environments may include an increase in the exploitation of krill for feeds (an important prey source for many megafauna species (Ducklow *et al.* 2007)) and an increase in the use of wild-caught juvenile finfish and crustaceans for rearing. Economically-disadvantaged developing countries may find themselves at even greater risk of forfeiting their own coastal environmental resources to wealthier countries and private interests (Primavera 1997; Alder and Watson 2007). Moreover, because technologies developed to improve production input efficiencies are closely guarded (UNEP 2007), innovations aimed at reducing ecological impacts are not widely shared or traded.

Mariculture development in a *Security First* world will not likely generate stronger negative effects for global marine and coastal environments than those in *Markets First*. This may, however, be solely by virtue of the fact that the global rate of production is decreased and the increase in total global production is constrained due to the global constriction of flows of people and trade. As such, the overall sustainability of the mariculture sector and its negative environmental effects are likely to be more locally variable; in some countries ecological damages may be much more serious than in a *Markets First* scenario. It could also be difficult to effectively quantify the global extent of ecological effects from an increase in mariculture production in a *Security First* world because of the strong de-emphasis on multilateral communication, cooperation, and development assistance. Conversely, however, the marine and coastal ecosystems of some countries may actually end up better protected. Further development in some countries, particularly on the African continent where sub-Saharan mariculture production has largely stagnated by the 21st century (FAO 2006), is likely to discontinue under *Security First* because of high production costs, a lack of global and local financial and institutional support for infrastructure and development, and increased market isolation.

While all four development scenarios incorporate concepts of sustainability into their framework, only *Sustainability First* prioritizes ecological considerations in development decision-making. With regards to mariculture, these strengthened ecological considerations may mean a return to more traditional and community-based farming models with a stronger stewardship role. Production of local bivalves and herbivorous finfish with a higher MSI, raised in poly-, integrated, and multi-trophic culture systems, may become more commonplace worldwide. Combined with a worldwide increase in the use of Marine Protected Areas management (UNEP 2007), some of the negative pressures on heavily used marine and coastal ecosystems may be mitigated or reduced. An increased focus on institutional cooperation, collaboration, and education at all levels, and in particular an increased valuation of the contributions and accountability of civil society will drive the shift in industry practices (UNEP 2007). The increased awareness of the environmental tradeoffs of mariculture development in this scenario will likely improve cooperation and compliance in environmentally-responsible development policies.

The above modifications to global mariculture development and the resulting decline in the global rate of mariculture production are likely to yield the lowest negative ecological tradeoffs by 2030 at both the global and local-scale, in spite of global production increases. However, as the global human population surpasses a projected 8.3 billion people by 2030 (UN 2009b), an increase in the pressure on the world's oceans and marine and coastal resources is inevitable. Furthermore, a *Sustainability First* approach to mariculture development does not negate global inequities in the distribution of production and profit (UNEP 2007), nor will it eliminate the demand for high value carnivorous species for consumption.

How likely is any one of these potential development scenarios to occur? Globally, a version of each key element explored within the scenario narratives is already reality. However, the uncertainty in foreseeing the future, the sheer complexity of global food production systems, and the lack of general consensus in what constitutes sustainable development in practice ensures that these scenarios will remain caricatures of only a few of the possible futures for the mariculture industry. In addition to managing and conserving our natural resource base and ensuring that human needs are met both now and in the future, sustainable development "must conserve land, water, plant and animal genetic resources, [be] environmentally non-degrading, technically appropriate, economically viable and socially acceptable" (FAO 1988). However, the social lens through which sustainable development concepts are ultimately conceived, accepted, and acted upon for the future, and the balance of priorities struck between economic, social, and environmental considerations, depends strongly on the current priorities of key actors around the world, and how they choose to navigate through a changing world.

When observing historical and extrapolated mariculture production trends at the country level, the simulated future global production trends are not as far-fetched as they might at first appear - mariculture production in most of the top 10 producing counties has also been steadily increasing since the 1970s and 80s. The baseline mariculture regression model, derived from current data trends, represents a reasonable basis for production simulation assumptions. Norway's baseline production simulation bears a striking resemblance to observed internal government projections of future mariculture production (Pauly, pers. comm., UBC, 2010). In countries such as Spain and Japan, which have more established production industries with lower growth rates (FAO 2006), simulated increases in future mariculture production have begun to level off in the baseline scenario by 2030. Even when considering the influence of demand constraints on global supply, a global review by Wijkstrom (2003) finds that patterns of population growth, combined with historical patterns of per capita fish consumption increase, indicate that the annual growth in the volume of fish demanded in the next twenty years is likely to be the largest before it tapers off in the decades beyond.

It is not practical to test the sensitivity of the scenario results against the many assumptions behind the simulation model, as also concluded by authors of the International Food Policy Research Institute's IMPACT model report (Delgado *et al.* 2003). However, the results presented here could perhaps benefit from a re-examination of the projections for countries where historical production trends are declining or highly variable in the 2000s (e.g., the Philippines and South Korea), though this would still not guarantee improved model accuracy when projecting future trends. In any case, the dramatic trends of increase in the simulated scenarios of future global mariculture production may provide a reasonable representation of a sector – mariculture - that, by 2030, will not have been significantly affected by either supply or demand constraints.

3.4.2 Main policy messages

The future of mariculture production and supply in the face of changing global development and environmental management paradigms is only one piece of a much larger future global fisheries outlook. A more complete analysis of aquaculture's future role in this regard should combine a similar analysis of the freshwater production environment. As in the original GEO-4 assessment (UNEP 2007), a number of main policy messages can be summarized from the scenario outcomes:

1. *Under the current development concepts, socio-economic considerations are likely to continue to trump ecological considerations in mariculture production for the foreseeable future*. Even under the thematic influence of "environment for development", all but one of the development scenarios continues to prioritize a worldwide expansion, production increase, and intensification of high-value, high-environmental input, carnivorous marine finfish and crustacean species. While market-driven choices are likely to increase total global mariculture production over the next two decades (as well as profits and some jobs), longer-term production growth may ultimately decrease in countries around due to environmental constraints. With many of the most serious negative ecological and social effects likely to be experienced by developing countries, the perceived benefits of market-driven pathways of action risk translating to only a privileged few people over a short time horizon.

2. *A widespread shift towards more ecologically sustainable mariculture production practices would not prevent us from meeting the currently projected future per capita consumption demand for food fish, from achieving economic growth, or from further sector development.* The most ecologically-focused *Sustainability First* scenario still increases and expands future global mariculture production and development. This occurs despite considerable reductions in mariculture growth rates. This scenario does suggest, however, that in order for such an outcome to be achieved, there is a need to change how we eat and value seafood, particularly in Western countries.

3. *Improving global environmental governance in mariculture production and development will require a multilateral increase in cooperation at all institutional levels.* However, the diversity of actors and drivers at play in the global mariculture sector means that a complete harmonization of decision-making at the global or regional scale is not realistic. Despite this, steps can be taken to facilitate more positive interactions within and between producing countries vis-à-vis the implementation of mariculture development policies with a stronger environmental focus. An increase in policies and assistance which promote the transfer and innovation of input-efficient production technologies, an increase in the level of general and technical education and support, improvements to the quality of statistical information systems, and input from civil stakeholders are a few ways in which to foster improved global-scale environmental governance.

4. *The issues are complex.* None of these development scenarios presents a utopian vision of a future where 'everyone wins'. Each action and development outcome has its risks, each benefit its costs. Mariculture development decisions are closely interlinked with other marine and coastal industries and activities, with terrestrial food production systems, with the availability of environmental resources such as land, water, and energy, and also with people. Each of these elements is shaped in turn by another set of actors, drivers, and assumptions. Regardless of the decision-making tools at our disposal and the insights and guidance they may generate, any course of action will involve making some tough choices, generating some creative solutions, and taking responsibility for our role as individuals.

One need not agree with all the assumptions or elements used in this analysis to derive value from it. The primary focus of such an undertaking is to enable more tangible ways in which to ask ‘what if’ and highlight the current role and impact of assumptions and choices made by individuals and groups on the future direction of aquaculture development. Under any scenario, and regardless of the balance of social, economic, and environmental considerations addressed, the global increases in both people and in food fish demand stands to further intensify the pressure placed on already heavily exploited coastal and marine resources as mariculture continues to generate products in response to market demand. International commitments to policies such as the FAO *Code of Conduct for Responsible Fisheries* (Article 9) (FAO 1995), dictate that we act responsibly when managing and developing our aquaculture resources. The existing social, environmental and regulatory issues of current mariculture production and development, widely discussed in the scientific literature, are currently at odds with these commitments. What is needed to move future mariculture development in a more responsible direction is a clearer vision of the potential options for action before us, as well as their potential consequences. The rewards of doing so are a global seafood industry, countries, people, and an environment with a better resilience and capacity to adapt to the uncertainties of the future.

Chapter 4

Conclusion

4.1 Discussion

Aquaculture's rapid global expansion over the past 30 years (FAO 2010c; Chapter 2), a growing human population and incomes, and declining rates of global fisheries catches (Watson and Pauly 2001; FAO 2010c), result in growing importance on this animal protein production sector for global food security (Ahmed and Lorica 2002; FAO 2003; Cunningham 2005). However, the sector's lasting impact on society and coastal and marine environments remains uncertain. Much of this uncertainty is driven by inadequate information, exacerbated by the worldwide shift of aquaculture from freshwater to marine and brackish environments (Goldburg and Naylor 2005; FAO 2006,2009e).

Uncertainty surrounding how much seafood is being produced, of what, and where makes it difficult to obtain a clear appreciation of the positive and negative effects of mariculture, particularly with regards to development that "[m]eets the needs of the present without compromising the ability of future generations to meet their own needs" (WCED 1987). Such uncertainties weaken our ability to effectively anticipate, adapt, plan, and meet international sustainable development commitments such as the Millennium Development Goals, Agenda 21, and the FAO Code of Conduct for Responsible Fisheries (UNCED 1992; FAO 1995; UN 2009a). Mariculture's predominant production of 'luxury' species provides an incentive for further subsector growth and development (FAO 2006,2009e). However, it is a subsector whose economic and social benefits strongly favour developed countries (Kent 1995). In addition, its reliance on environmental inputs to maintain the high rates of production make it widely unsustainable (Naylor *et al.* 2000; Delgado *et al.* 2003; FAO 2006; Primavera 2006).

To improve the quality of information available for analysis and to improve our understanding of historical global aquaculture sector trends and their broader context in global fisheries, the second chapter of this thesis described the construction of a global database of marine and aquaculture production from 1950 to the present. This Global Marine Production Database (GMPD) distinguishes itself from the FAO Global Aquaculture Production database mainly in that it presents global mariculture production at a finer taxonomic and geographic resolution, thus avoiding many of the potential inaccuracy issues of production data aggregated at the national scale. However, the collection, compilation, and analysis of the *Sea Around Us* Project's GMPD, described in Chapter 2, found an overall similarity in the global, regional, and taxonomic trends between the two datasets. This implies that our current understanding of broader historical mariculture production trends is reasonably accurate. The spatial GIS maps generated from the GMPD database also provide additional options for analysis, by enabling the visualization of linkages between mariculture, capture fisheries and other coastal activities at smaller scale. This should allow, as well, for more focused ecosystem-wide mitigation measures and better spatial planning of marine and coastal areas.

This work, which provides more detailed global mariculture production information, thus dispels some informational uncertainties in global aquaculture production trends. Moreover, it also identifies the need for continued worldwide improvements to mariculture data quality, in the interest of working towards the FAO *Code of Conduct for Responsible Fisheries'* mandated "best scientific evidence available" for decision-making (FAO 1995). This need is acute in China, the world's largest producer of seafood products, and a country with well-documented data accuracy issues (Rana *et al.* 1998; Watson and Pauly 2001; FAO 2010c; Zhijie et al. 2008; Batson 2010). These worldwide improvements to data include a need for more complete, accurate, transparent, and timely reporting from FAO member nations, a strengthening of ongoing efforts to improve the quality of Chinese aquaculture statistics, and a stronger clarification of the FAO's statistical standards and classifications for aquaculture reporting, particularly with respect to practices with overlapping characteristics between aquaculture and fisheries.

Regardless of the uncertainty remaining in country-level mariculture production trends, the dramatic worldwide increase in the total tonnage of seafood produced through mariculture since 1950, and particularly since 1970, is irrefutable. As our population and our demand for seafood continues to grow in coming decades, the decisions we make today will define how future mariculture development is undertaken, food security and other social goals are met, and how we anticipate, mitigate, and manage the inevitable social and ecological tradeoffs. With sustainability concepts becoming more prevalent in development policies worldwide, it is not a question of whether production in the currently widely unsustainable commercial mariculture sector will be affected in the coming decade, but rather how.

As a policy exercise designed to clarify potential options, pathways, and tradeoffs for action for the future of mariculture production and development, highlight linkages and issues, and provide additional information to policymakers, Chapter 3 builds off of both the reconstructed and re-evaluated trends from Chapter 2 and the conceptual framework of the United Nations Global Environmental Outlook (GEO-4) "environment for development" scenarios. The GEO-4 framework methodology and underlying assumptions are applied to the exploration of four possible mariculture development futures to 2030; this analysis of potential future global industry and production trends is the first of its kind specific to mariculture, and one of the few undertaken for aquaculture. This chapter concludes that aquaculture development worldwide, as currently influenced by broadly defined concepts of sustainability, is still primarily focused on addressing shorter-term socio-economic goals over the maintenance and restoration of healthy aquatic ecosystems in the context of longer-term strategies. Given the simulated future mariculture production trends, and the current knowledge and trends in food fish supply and demand from which they are constructed, the global mariculture scenarios indicate that with freshwater aquaculture's assistance, we can supply currently projected food fish demand, at least in the next two decades. However, these scenarios also imply that without a stronger and more widespread consideration of ecological concepts in mariculture development, the realization of this goal may in reality be compromised.

In this regard, the scenario explorations in Chapter 3 identify mariculture's dependence on wild resources, such as feed and juveniles, as input to the farming of high-value carnivorous species. Thus, competition for resources with other marine and coastal activities, and the subsector's potential for damage to aquatic ecosystems through intensive industrial monoculture production practices, are major obstacles to ensuring that global food security goals are met and development tradeoffs are minimized. Also, while we may succeed in sustaining or increasing current levels of mariculture production worldwide by 2030 along conventional development pathways (i.e., those with minimal ecological constraints), and supply Western markets, these scenarios imply that mariculture's current flow of social benefits from poor to rich will be maintained or even exacerbated.

There are no guarantees to how the future might unfold, particularly when analysing the outcomes of human interactions with complex food systems. There are no easy solutions to increasing global food production for a growing population either, with everyone and everything, including the environment, coming out ahead. However, the analyses in Chapter 3 envision what it might take to follow more socially and ecologically responsible mariculture development pathways, beginning with a dramatic re-evaluation of how we value seafood, particularly in the West. This is a major social undertaking requiring significant cooperation, collaboration, and information-sharing at a range of institutional levels if it is to succeed. Actions to this end may include shifting the focus of commercial mariculture production and marketing towards the poly- and integrated culture of species with lower trophic levels and native to the country of production, sharing technologies and practices that promote efficient resource use, reducing the use of chemicals and pharmaceuticals in production, and promoting and making more informed consumer choices. These tradeoffs may result in a slowing of global aquaculture's annual production increase;

however, these tradeoffs would not prevent us from meeting current global food fish security goals. Rather, they would enable this achievement to be sustainable.

However, these possible action pathways also have the potential to further disadvantage those in developing countries and regions and still require us to make tough decisions about the sustainability of the seafood we eat. Continuing to produce and sell the type of seafood that we are currently demanding year-round and at a desired price may lead to increased genetic manipulations of the reproduction, growth and food conversion of highly desired species, in order to reduce per-unit resource input needs. The protection of marine and coastal environments from further modifications and damages due to future mariculture expansion and development activities may require a focus on even more intensive and more self-contained production practices, both physically and geographically, rather than on extensive systems which tend to have a sizable geographic footprint, comparatively lower rates of production, and less overall control over factors of production.

4.2 Strengths and Weaknesses

The collection and synthesis of over five decades' worth of mariculture production statistics across all of the species and maritime provinces of more than a hundred maritime countries, including their mapping using GIS, was a major undertaking and the first known reconstruction of its kind. While the work provides a newly spatially and taxonomically refined global dataset for use in analyses of the global mariculture sector, a task of this size involves logistical constraints with respect to sourcing and verifying officially reported data. A reliance on online statistics and correspondence was more successful for some countries and for some decades than others. In many countries, the lack of data at the desired resolution for analysis means that unresolved uncertainties remain at global, regional, and country-levels. No analyses have been conducted to attempt to quantify the disparity between 'true' and reported global aquaculture production; however, such uncertainties could be addressed in the future by adding a data 'pedigree' to provide a metric of global data integrity and transparency (Funtowicz and Ravetz 1990). Such a pedigree could also assist in quantifying the extent to which mariculture's increasing trends can be attributable to improved reporting over time. It has been previously stated that the data collected in Chapter 2 should be considered with caution when used at the country level due to these same unresolved issues of data uncertainty. It should also be noted that the spatial scale of the data, while more refined than the FAO datasets, remains too coarse to be applicable for most marine planning analyses, which tend to be localized.

The analysis in Chapter 3 reinforces the view that commercial mariculture, while strongly linked to the capture fisheries and freshwater aquaculture sectors, is a distinct food fish production sector with separate actors, drivers, issues, and uncertainties which influence development. Thus, it should not be lumped together as part of "fisheries" in analyses of the future demand and supply. However, the policy exercise in Chapter 3 also required simplifications to complex global systems; as such, important details may not be given the necessary recognition. One such detail is the exclusion of environmental state change variables as a factor influencing global aquaculture production. These variables, such as a change in oceanic and coastal conditions and a subsequent reduction in suitable farm area brought about by global climate change, were held constant in the scenarios in order to keep the focus of the analyses on human drivers of decision-making. It is fairly obvious, however, that changes in oceanic conditions from climatic factors could have potentially major effects on global mariculture production and development, as noted in their impact on marine fisheries (Cheung *et al.* 2010).

Other simplifications are evident in the simulation component of the scenario outputs. These more quantitative production simulations are based on simple (if segmented) regression models and a set of decisions rules which are defensible for the extrapolation of a global level mariculture production trend but which are overly simplistic when applied to some of the more highly variable past production trends at the country level. Another simplification, which is addressed in the narratives but only indirectly in the simulations, is the exclusion of demand-side price drivers on global mariculture supply. The simulated production trends in Chapter 3 appear much greater than in the compared demand-driven models (which only peripherally touch on supply-side drivers). These simplifications are one reason why the mariculture scenarios are intended as theoretical conceptualizations of 'what could be' rather than forecasts of 'most likely' or recommendations of what 'should be'. However, given the uncertainties associated with forecasting, there is no guarantee that the addition of variables to increase model complexity will reduce the uncertainties associated with scenario projections.

4.3 Future Work

The usefulness of the reconstructed database of global mariculture production and the analyses in Chapter 2 can be further improved upon and the applications diversified by updating the database to the current year, by replacing estimated data with official statistics as they become available and supplemented data with estimates, and by further refining the taxonomic and geographic resolution of production data in countries where reported statistics are provided at a resolution finer than currently requested by the FAO. Adding a coordinate-based component to the GIS representation of mariculture production could also contribute positively to analyses informing the policy and management of more environmentally sustainable marine and coastal resource use. Also, more in-depth analysis of the production trends of individual countries could assist in identifying problem areas in reported data and lead to further improvements in data accuracy. Finally, an estimate of unreported global mariculture production could be sought through a comparison of reported imports and exports to reported production.

With regards to the policy exercise of future global mariculture development undertaken in Chapter 3, in view of changing global views on development and environmental management, the future of mariculture production and sector growth as well as their potential effects on people and on the environment are only two pieces of a much larger future global seafood production outlook. In addition to integrating information from projection of future fisheries trends, a more complete analysis of aquaculture's future role in the global fisheries outlook should combine a similar analysis of the freshwater production environment. The importance of this analysis of mariculture's potential development trends in providing additional information to decision-makers does not lie in the accuracy of its predictions. Given the unpredictability of the future, the strength of this work rests instead in its ability to provoke thought and discussion regarding the possibilities for future mariculture development, how and why we might arrive at such a future, and what the potential social, economic, and environmental implications of decisions might be on interconnected, broader global systems.

The re-constructed database and analyses undertaken in this thesis are part of a broader body of work conducted by the *Sea Around Us* project to improve global information systems and to clarify the impact of fisheries on the world's marine ecosystems (Pauly 2007). As such, this work can be used as both an complement and an enhancement to preexisting databases and analyses, specifically the FAO's *Global Aquaculture Production Database* (FAO 2009b), IFPRI and Delgado *et al.*'s (2003) Fish to 2020, and UNEP's *Millennium Ecosystem Assessment* and *Global Environmental Outlook 4* (UNEP 2006,2007). These efforts represent a step towards helping to improve the quality and integrity of data used in scientific analyses that better inform effective fisheries and aquaculture management and policies which are socially, ecologically, and economically sustainable.

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Appendices

Appendix A: Appendix to Chapter 2

List of primary data sources by region

Table A.1: List of primary data sources for GMPD, by region. These sources represent the most relevant documents from which production statistics and other key industry information was obtained. They do not represent all literature consulted for a given country. The notation **'NBR'** refers to data presented **'**Not By Region' (i.e., national data only).

Primary References: Africa		
Country	**Source**	**Type of Information**
Algeria	FAO. © 2006-2011. Vue générale du secteur aquacole national. Algérie. National Aquaculture Sector Overview Fact Sheets. Texte par Moussi, N. *In*: *Département des pêches et de l'aquaculture de la FAO* [en ligne]. Rome. Mis à jour 2 March 2006. URL: www.fao.org/fishery/countrysector/naso_algeria/fr. Accessed 26 January 2007.	Industry history, species, environments, locations of production
	FAO. 2008. FishStat Plus: Universal software for fishery statistical time series. "Aquaculture production 1950 – 2006". Version 2.31. FAO Fishery Information, Data and Statistics Unit.	Production, all species 1984 - 2004
	FAO. 1988. Situation of aquaculture in the MEDRAP (Mediterranean Regional Aquaculture Project) countries. "Algeria". Mediterranean Regional Aquaculture Project. FAO. 63 p. URL: www.fao.org/docrep/field/007/af05e/AF025E02.htm. Accessed 7 March 2007.	Production of shrimp, oyster, mussel 1984, location
	Chalabi, A. 2000. L'aquaculture en Algerie et son context Maghrebin. FAO-SIPAM. 39p.	Species, production in Mellah, other region info
Eritrea	The Seawater Foundation. 2004. Seawater Farms Eritrea. URL:www.seawaterfoundation.org/newSite/swEritrea.htm.Accessed 2007.	Shrimp production estimate 1999-2004 - *Pers. Comm. Email from S.F. in hardcopy file indicates there is no longer any aquaculture as of 2004*
Egypt	El Gayar, O., Goulding, I. 2001. Marine aquaculture in Egypt. "Production and marketing of fish in Egypt. Megapesca Lda. Portugal. URL: www.megapesca.com/acrobat/Egypt.pdf. Accessed 2007.	Production by species 1998, 2000, ratios of production 1992-2000, *paper notes production of some species of 'doubtful validity'*
	FAO. © 2003-2010. National Aquaculture Sector Overview. Egypt. National Aquaculture Sector Overview Fact Sheets. Text by Salem, A.M.; Saleh, M.A. *In*: *FAO Fisheries and Aquaculture Department* [online]. Rome. Updated 10 August 2006. URL: http://www.fao.org/fishery/countrysector/naso_egypt/en. Accessed 16, June, 2010.	Sector history, species and farm location info
	Sadek, S. 2000. Sea bream culture in Egypt: status, constraints and potential. Fish Physiology and Biochemistry. 22:171-178.	Species, location info for sea bream, production of main species (seabass, bream, mullet, prawn) 1997
	FAO. 2008. FishStat Plus: Universal software for fishery statistical time series. "Aquaculture production 1950 – 2006". Version 2.31. FAO Fishery Information, Data and Statistics Unit.	Production, all species 1985-1991, (2001-2004??)
Kenya	Padlan, P.G. 1981. Report on Consultancy Kenya Brackishwater Aquaculture Project. UNEP/FAO. 29 p. URL: http://www.fao.org/docrep/field/003/AC569E/AC569E00.htm#TOC.Accessed March 15, 2011	Location of farm site
	FAO. 2008. FishStat Plus: Universal software for fishery statistical time series. "Aquaculture production 1950 – 2006". Version 2.31. FAO Fishery Information, Data and Statistics Unit.	Penaeus shrimps 1983-2004

Table A.1 Continued		
Primary References: Africa		
Country	**Source**	**Type of Information**
Libyan Arab Jamahiriya	FAO. © 2006-2011. National Aquaculture Sector Overview. Libyan Arab Jamahiriya. National Aquaculture Sector Overview Fact Sheets. Text by Ghebli, H.M. In: *FAO Fisheries and Aquaculture Department* [online]. Rome. Updated 21 March 2006. [Cited 9 February 2011]. URL: http://www.fao.org/fishery/countrysector/naso_libya/en	Sector history, species and farm location info, estimate of production of marine fish 1991-97**,** 2004 Tuna production est. 2003
	FAO. 2007. Cage aquaculture – Regional reviews and global overview. Halwart, M., Soto, D., Arthur, J.R. (eds). FAO Fisheries Technical Paper. No. 498. Rome. 240 p.	Locations of sea cages, production seabass and seabream 2004, tuna 2003
Madagascar	HydroTech Solutions. 2006. Projects-Madagascar. URL: http://jm.amouroux.free.fr/Madagascar.htm. Accessed 2006.	Locations of farms as of 2004, some farm info
	FAO. 2008. FishStat Plus: Universal software for fishery statistical time series. "Aquaculture production 1950 – 2006". Version 2.31. FAO Fishery Information, Data and Statistics Unit.	P. mondon production 1990-2004
Mauritius	MFMR. 2007. Annual Report. Section 3 – Aquaculture. Ministry of Fisheries and Marine Resources. Albion Fisheries Research Centre. 8 p.	Species info, production by species NBR 2006
	Government of Mauritius. 1987. Report of the Technical Committee on Fisheries Research. 14 p. URL: www.gov.mu/portal/sites/ncb/moa/farc/fish.pdf. Accessed April 29, 2008.	Marine barachois production 1977-1985
	Bhikajee, M. 1997. Recent advances in aquaculture in Mauritius. Food and Agricultural Research Council (AMAS). Réduit. 95-102 pp.	Sector history, species, locations, production marine shrimp, barachois spp. 1991-1995
	FAO. 2008. FishStat Plus: Universal software for fishery statistical time series. "Aquaculture production 1950 – 2006". Version 2.31. FAO Fishery Information, Data and Statistics Unit.	Mollusk, crustacean, marine fishes NBR 1990, 1996-2006 *– used as baseline for disaggregation*
Mayotte	IFREMER. 2007. Aquaculture – Fish. Institut français de recherché pour l'exploration de la mer [online]. URL: www.ifremer.fr/aquaculture/en/fish/discover_fishes.htm. Accessed 2007.	Production of ombrine 1998-2005, *took % of 'overseas'production #s*
Morocco/W. Sahara	Massik, Z. 2000. Main constraints of aquaculture in Morocco. Globefish publication.3p. URL: www.globefish.org/upl/Aquaculture/power%20point/Morocco.pdf. Accessed 2006.	Sector overview, main species of culture, some location info
	MPM. 2006. Ressource – Statistiques [online]. "Evolution de la production aquacole 1990-2004". Département de la Pêche Maritime. Ministère de l'Agriculture et de la Pêche Maritime. URL: http://www.mpm.gov.ma/. Accessed 2006.	Production of anguille, crevettes, daurade, huitre, loup, palourde, moule 1990-2004
	FAO. © 2006-2011. Vue générale du secteur aquacole national. Maroc (le). National Aquaculture Sector Overview Fact Sheets. Texte par Abdellatif, O.; El- Ahdal, M. In: *Département des pêches et de l'aquaculture de la FAO* [en ligne]. Rome. Mis à jour 1 February 2005. URL: www.fao.org/fishery/countrysector/naso_morocco/fr. Accessed 2006.	Sector overview, main species of culture, some location info
	FAO. 2008. FishStat Plus: Universal software for fishery statistical time series. "Aquaculture production 1950 – 2006". Version 2.31. FAO Fishery Information, Data and Statistics Unit.	Pacific cup oyster 1966-1989
Mozambique	FAO. ©2006-2008. National Aquaculture Sector Overview - Mozambique. Text by Omar, I. In FAO Fisheries and Aquaculture Department [online]. Rome. Updated 10 Oct 2005. URL: www.fao.org/fishery/countrysector/naso_mozambique. Accessed 5 Aug 2008.	Sector overview species produced
	FAO. 2008. FishStat Plus: Universal software for fishery statistical time series. "Aquaculture production 1950 – 2006". Version 2.31. FAO Fishery Information, Data and Statistics Unit.	Penaeus indicus and p. monodon 2000-2004
Namibia	NEPAD. 2005. Government of the Republic of Namibia Bankable Investment Project Profile. *"Support to Aquaculture Development"*. New Partnership for Africa's Development/FAO. Vol 7. 29 p.	Species of culture and general locations
	FAO. 2008. FishStat Plus: Universal software for fishery statistical time series. "Aquaculture production 1950 – 2006". Version 2.31. FAO Fishery Information, Data and Statistics Unit.	Production of oyster, mussel 1990-2004, abalone 2001-04

Table A.1 Continued		
Primary References: Africa		
Country	**Source**	**Type of Information**
Nigeria	FAO. 2008. FishStat Plus: Universal software for fishery statistical time series. "Aquaculture production 1950 – 2006". Version 2.31. FAO Fishery Information, Data and Statistics Unit.	Marine fish nei 1972-1995 *Fao mentions data are likely not reliable*
	Shipton, T., Hecht., T. (eds). 2005. A synthesis of the formulated animal and aquafeeds industry in sub-Saharan Africa. CIFA Occasional Paper. No. 26. FAO, Rome. 61 p.	Information on specied produced
Réunion (FR)	IFREMER. 2006. Pisciculture marine dans l'outre mer Français. "La Réunion". 131-132 pp. *In:* Pisciculture marine – Eléments de prospective. Association for the Development of Aquaculture / Institut Français de Recherche pour l'Exploration de la Mer.	Ombrine 2005, *indication in other literature of marine fishes 1985-87*
Senegal	Diallo, A. 2006. Aquaculture Development and Potentially Harmful Microalgae in Senegal. Presentation at 12th International Conference on Harmful Algae. Copenhagen 4 – 8 September, 2006.	Geographic regions of production by broad species
	Diallo, A. 2000. Status of fish stocks in Senegal. P. 38-40. *In*: Abban, E.K., Casal, C.M.V., Falk, T.M., Pullin, R.S.V. (eds). 2000. Biodiversity and sustainable use of fish in the coastal zone. ICLARM conf. Proc. 63:71p.	Oyster sp produced, location, some #s
	SFP Programme. 2007. Country Profile – Republic of Senegal. URL:www.sfp-acp.eu/EN/Pays/Africa/Senegal/SenegalCountryProfile.pdf Accessed 2008.	Geographic regions of production by broad species, prod of oyster 00,03
	FAO. 2008. FishStat Plus: Universal software for fishery statistical time series. "Aquaculture production 1950 – 2006". Version 2.31. FAO Fishery Information, Data and Statistics Unit.	National production of cupped oyster 01-05, 88-70, gasar oyser 06-04,03,01, c. gigas 05-01 - *99% of production data*
Seychelles	Seychelles Government. 1997. Seychelles national biodiversity strategy and action plan. Seychelles First National Report to the Convention on Biological Diversity. Mahe. 44 p.	Aquaculture sector info, species, location, *p. monodon* production 1994-96
	SFA.2001/2006. Annual Report. Seychelles Fishing Authority. Mahe. URL: www.sfa.sc/. Accessed April 29, 2008.	Prawn production at Coetivy 1995-2001, 2002–06 (graph), *giant clam are ornamental source: SMB/MISD*
	FAO. © 2004-2011. Fishery and Aquaculture Country profiles. Seychelles. Fishery and Aquaculture Country Profiles. In: *FAO Fisheries and Aquaculture Department* [online]. Rome. Updated 5 August 2004. URL: http://www.fao.org/fishery/countrysector/FI-CP_SC/en. Accessed July 7, 2007.	Sector info, species, locations
	FAO. 2008. FishStat Plus: Universal software for fishery statistical time series. "Aquaculture production 1950 – 2006". Version 2.31. FAO Fishery Information, Data and Statistics Unit.	'Crustaceans' NBR 1989-1993 – *pearl harvesting exists, no #'s found, giant clam also (not for consump?)*
South Africa	FAO. © 2004-2011. Fishery and Aquaculture Country profiles. South Africa. Fishery and Aquaculture Country Profiles. *In:* FAO Fisheries and Aquaculture Department [online]. Rome. Updated 1 January 2010. URL: www.fao.org/fishery/countrysector/FI-CP_ZA/en. Accessed March 19, 2007.	Sector info, species, some locations, production 2003
	Sadek, S., Rafael, R., Shakouri, M., Rafomanana, G., Ribeiro, F.L., Clay, J. Shrimp Aquaculture in Africa and the Middle East: The Current Reality and Trends for the Future. Report prepared under the World Bank, NACA, WWF and FAO Consortium Program on Shrimp Farming and the Environment. Work in Progress for Public Discussion. Published by the Consortium. 42 pages.	Shrimp production 1992-2000, locations, species
	Britz, P., Hecht. T. 2007.The Outlook for Aquaculture Development in Southern Africa. Rhodes University/Enviro-Fish Africa. PowerPoint presentation.	Locations of farms
	FAO. 2008. FishStat Plus: Universal software for fishery statistical time series. "Aquaculture production 1950 – 2006". Version 2.31. FAO Fishery Information, Data and Statistics Unit.	Abalone 1993-2004 Med. Mussel 1974-2004 Sea mussel 1992-2004 Pac. Cup oyster 1985-2004 Mullet 1985-89 Mactra 1986-91 Carpet shell 1988-90

Table A.1 Continued

Primary References: Africa

Country	Source	Type of Information
Tunisia	FAO. © 2006-2011. Vue générale du secteur aquacole national. Tunisie. National Aquaculture Sector Overview Fact Sheets. Texte par Missaoui N.*In*: Département des pêches et de l'aquaculture de la FAO [en ligne]. Rome. Mis à jour 1 August 2005. URL: http://www.fao.org/fishery/countrysector/naso_tunisia/fr. Accessed August 24, 2007.	Species info, some locations, production 2000-2004 (from FAO) Tuna production 2003/04
	Bruno. 1988. Situation of Aquaculture in the MEDRAP Countries. "Tunisia". Projet Regional Mediterraneen de Development de l'Aquaculture. FAO, Rome. 61 p.	Information on culture locations of main species
	Bendag, M. 1995. Systèmes de production du loup et de la daurade. Elevage intensif en basins en Tunisie. *In*: Aspects économiques de la production aquacole = Aquaculture production economics. Zaragoza: CIHEAM-IAMZ, 1995. p. 97-112: 2 ill. 9 graphs, 8 graphs. (Cahiers Options Méditerranéennes ; v. 14), Seminar of the CIHEAM Network on Socio-economic and Legal Aspects of Aquaculture in the Mediterranean (SELAM), 1995/05/17-19, Montpellier (France)	Map of farming sites, year of farm creation, bar graphs of production (not used)
	FAO. 2008. FishStat Plus: Universal software for fishery statistical time series. "Aquaculture production 1950 – 2006". Version 2.31. FAO Fishery Information, Data and Statistics Unit.	Flathead mullet, Med. Mussel, Pacific cup, Gilthead seabream, European seabass 1978 – 2004

No Commercial Mariculture production as of 2004 in: Angola, Benin, Cameroon, Cape Verde, Comoros, Congo, Congo Dem. Rep., Côte D'Ivoire, Djibouti, Gabon, Gambia, Ghana, Guinea, Guinea Bissau, Equatorial Guinea, Liberia, Mauritania, St. Helena, Sao Tome and Principe, Sierra Leone, Somalia, Sudan, Tanzania, Togo

Table A.1 Continued		
Primary References: Americas		
Country	**Source**	**Type of Information**
Argentina	Panne, Santiago. 2008. Producción por acuicultura en Argentina 1998 – 2006. Personal Communication. Ministerio de Agricultura, Ganadería y Pesca. Dirección de Acuicultura (SAGPyA). 1 p.	Production NBR *for C. gigas, M. platensis/ M. chilensis* 1998 - 3006
	FAO. © 2007-2010. National Aquaculture Sector Overview. Argentina. National Aquaculture Sector Overview Fact Sheets. Text by Wicki, G. A. In: *FAO Fisheries and Aquaculture Department* [online]. Rome. Updated 1 January 2005. URL: http://www.fao.org/fishery/countrysector/naso_argentina/en. Accessed 29 January, 2007.	Industry history, species and environments of production, 2003 production of oyster and mussel – *data from Dirección de Acuicultura.*
	Ministerio de Agricultura, Ganadería y Pesca. El cultivo de los moluscos bivalvos marinos en Argentina. Dirección de Acuicultura (SAGPyA) URL:www.sagpya.mecon.gov.ar/new/0-0/pesca/acuicultura/marina/moluscos.php. Accessed March 2008.	Species and general locations of production
Bahamas	FAO. 2008. FishStat Plus: Universal software for fishery statistical time series. "Aquaculture production 1950 – 2006". Version 2.31. FAO Fishery Information, Data and Statistics Unit.	Production of *p. vannamei* for all years 1984 – 2005
	FAO. 2002. Report of the subregional workshop to promote sustainable aquaculture development in the small island developing states of the Lesser Antilles. FAO Fisheries Report No. 704. 4 – 7 November, 2002. St. Lucia.	Shrimp species and location of production
Belize	FAO. © 2006-2010. National Aquaculture Sector Overview. Belize. National Aquaculture Sector Overview Fact Sheets. Text by Myvett, G. In: *FAO Fisheries and Aquaculture Department* [online]. Rome. Updated 1 February 2005. URL: http://www.fao.org/fishery/countrysector/naso_belize/en. Accessed January 29, 2007.	Industry history, species, environments, locations of production
	FAO. 2008. FishStat Plus: Universal software for fishery statistical time series. "Aquaculture production 1950 – 2006". Version 2.31. FAO Fishery Information, Data and Statistics Unit.	Production NBR for whiteleg shrimp all years 1984 to 2005, except 01,02
	Ministry of Agriculture and Fisheries. 2003. Annual Report 2002. Belize Fisheries Department. Belize City. 13 p.	Industry information, 2002 production of head-on shrimp
Brazil	FAO. © 2005-2010. National Aquaculture Sector Overview. Brazil. National Aquaculture Sector Overview Fact Sheets. Text by Suplicy, F.M**.** In: *FAO Fisheries and Aquaculture Department* [online]. Rome. Updated 1 June 2004. URL:.http://www.fao.org/fishery/countrysector/naso_brazil/en. Accessed December 2005	Industry history, species, environments, locations of production
	Roubach, R., Correia, E.S., Zaiden, S. Martino, R. C., Cavalli, R.O. 2003. Aquaculture in Brazil. World Aquaculture. p. 28 -35.	Industry history, species, environments, locations of production
	Ministério de Meio Ambiente (MMA). 2001 – 2006. Estatística da pesca 2000, 2001, 2002, 2003, 2004, 2005 Brasil. Grandes regiões e unidades da federaçã. Instituto Brasileiro do Meio Ambiente e dos Recursos (IBAMA). Brasilia.	Mariculture production of fish, crustaceans, molluscs by regions and smaller admin, breakdown by major species as well 2000 - 2005
	FAO. 2008. FishStat Plus: Universal software for fishery statistical time series. "Aquaculture production 1950 – 2006". Version 2.31. FAO Fishery Information, Data and Statistics Unit.	Production NBR for all species 1973-2000

Table A.1 Continued		
Primary References: Americas		
Country	**Source**	**Type of Information**
Canada	Fisheries and Oceans Canada (DFO). 2009. Canadian aquaculture production statistics. Statistical Services. URL: www.dfo-mpo.gc.ca/stats/aqua/aqua-prod-eng.htm. Accessed Feb 8th, 2010	Production by broad species groups by province 1986-2008 – *datasheets not complete for all spp in all provs*
	Ministry of Agriculture and Lands BC.2004. Salmon aquaculture in British Columbia. Fisheries Statistics. URL: www.agf.gov.bc.ca/fish_stats/statistics-aqua.htm. Accessed 2005. Ministry of Agriculture and Lands BC.2004. Shellfish aquaculture in British Columbia. Fisheries Statistics. URL: www.agf.gov.bc.ca/fish_stats/statistics-aqua.htm. Accessed 2005. Ministry of Agriculture and Lands BC.2004. British Columbia aquaculture species as of December 31, 2003. Fisheries Statistics. URL: www.agf.gov.bc.ca/fish_stats/species_list.htm. Accessed 2005.	Salmon species production 1998-2003 Shellfish by broad species 98-03 List of species cultured
	Ministry of Environment. 2009. BC Cultured shellfish production. Seafood statistics. Oceans and Marine Fisheries Branch. URL: www.env.gov.bc.ca/omfd/fishstats/graphs-tables/farmed-shellfish.html. Accessed Feb 8th, 2010. Ministry of Environment. 2009. BC Cultured salmon. Seafood statistics. Oceans and Marine Fisheries Branch. URL: www.env.gov.bc.ca/omfd/fishstats/graphs-tables/farmed-salmon.html. Accessed Feb 8th, 2010.	Shellfish prod by broad species 99-2008 Salmon prod by broad species 1999-2008
	Agriculture, Pêcheries et Alimentation Québec. 2002. L' État de la mariculture au Québec. Les ventes des enterprises maricoles par espèces principales en quantité (tonnes). URL: www.mapaq.gouv.qc.ca/Fr/Peche/md/statistiques/pecheaquaculture/mariculture/ . Accessed 2005. Agriculture, Pêcheries et Alimentation Québec. 2007. Pêches et aquaculture commercials au Québec en un coup d'oeil. Portrait statistique. 26p.	Shellfish production 1996-2003 Average shellfish production 2000-04, 05, 06 (est)
	Government of Nova Scotia.2005. Production sales of market sized products. Agriculture and Fisheries. URL: www.gov.ns.ca/nsaf/aquaculture/stats/index.shtml. Accessed 2005. Government of Nova Scotia. 2009. Production sales of market sized products. Agriculture and Fisheries. URL: www.gov.ns.ca/fish/aquaculture/stats/. Accessed Feb 8th, 2010.	Production by species/species mix 1994-2004 Production by species/species mix 1994-2008
	New Brunswick. 2003-2005. Agriculture, Fisheries and Aquaculture Sectors in Review 2002-2004. Department of Agriculture, Fisheries and Aquaculture. URL: http://www.gnb.ca/0027/index-e.asp. Accessed 2005.	Production by major species 2000-2004- *some data from DFO*
	Prince Edward Island Fisheries, Aquaculture and Rural Development.2009. Fishery Statistics 2007. URL: www.gov.pe.ca/infopei/index.php3?number=1099&lang=E. Accessed Feb 8th, 2010. Prince Edward Island Aquaculture Alliance. 2009. URL: www.aquaculturepei.com/. Accessed Feb 8th, 2010.	Production 1982-2007 by broad species Info on more individual species cultured
	Department of Fisheries and Aquaculture - Newfoundland Labrador. 2004. Aquaculture production and value. Statistics – Aquaculture. URL: www.fishaq.gov.nl.ca/aqua/aqua.stm. Accessed 2005. Department of Fisheries and Aquaculture - Newfoundland Labrador. 2009. Aquaculture highlights. Statistics – Aquaculture. URL: www.fishaq.gov.nl.ca/stats/index.html . Accessed Feb 8th, 2010.	Production by species 1998-03 Production by broader species 2005-08

Table A.1 Continued

Primary References: Americas		
Country	**Source**	**Type of Information**
Chile	Sernapesca. 2005. Publicaciones – Anuarios Estadísticos. "Chile, Cosecha de centros de acuicultura por especie y region". Servicio Nacional de Pesca. URL: www.sernapesca.cl/paginas/publicaciones/anuarios/index_anuario.php#. Accessed August 8, 2005.	Production by region (roman nums.) by species 1999 - 2004
	FAO. 2005. FAOMAP Detail Map [online]. URL: http://apps3.fao.org/faomap/. Accessed August 8, 2005.	Map of Chilean regions
	FAO. 2008. FishStat Plus: Universal software for fishery statistical time series. "Aquaculture production 1950 – 2006". Version 2.31. FAO Fishery Information, Data and Statistics Unit.	Production 1950 – 1998 Included for this analysis only; FAO data not in underlying database
Colombia	FAO. © 2008-2011. National Aquaculture Sector Overview. Visión General del Sector Acuícola Nacional - Colombia. National Aquaculture Sector Overview Fact Sheets. Text by Salazar Ariza, G. In: *FAO Fisheries and Aquaculture Department* [online]. Rome. Updated 1 February 2005. URL: www.fao.org/fishery/countrysector/naso_colombia/en. Accessed 26 January, 2011.	Industry history, species, environments, general locations of production
	INCODER. 2004. "Produccion de pesca y acuicultura en Colombia". Instituto Colombiano de Desarrollo Rural.	Cultured prawn production 1991-2004 NBR, pisciculture category too general to use, *data provided by Dr. J. Wielgus (WRI)*
	Ariza, G.S. 1999. Situacion de la acuicultura rural de pequeña escala en Colombia, importancia, perspectivas y estrategias para su desarrollo. FAO. 26 p.	Proportions of production for main species, species cultured, Prawn 1990 -1998, oyster 1998
	Ariza, G.S. 2002. El cultivo de organismos acuaticos en pequeña escala en Colombia. Ministerio de Agricultura y Desarollo Rural. Instituto Nacional de pesca y acuicultura (INPA). Bogotá. 31 p.	Species cultured, general locations, oyster 1996 - 2000
	FAO. 2008. FishStat Plus: Universal software for fishery statistical time series. "Aquaculture production 1950 – 2006". Version 2.31. FAO Fishery Information, Data and Statistics Unit.	*p. vannamei* 1976-1990
Costa Rica	FAO. © 2005-2010. National Aquaculture Sector Overview. Costa Rica. National Aquaculture Sector Overview Fact Sheets. Text by Zamoa Ovares, G. In: *FAO Fisheries and Aquaculture Department* [online]. Rome. Updated 1 February 2005. URL: www.fao.org/fishery/countrysector/naso_costarica/en. Accessed 26 January, 2007.	Industry history, species, environments, general locations of production Production of camarón and langostino 2000-2004 *data from Incopesca*
	INCOPESCA. 2005. Acuícultura en Costa Rica. "Producción Acuícola Según Especie". El Instituto Costarricense de Pesca y Acuicultura URL: www.incopesca.go.cr/Acuicultura.htm. Accessed January 2007.	*p. vannamei 2000-2004*
	FAO. 2008. FishStat Plus: Universal software for fishery statistical time series. "Aquaculture production 1950 – 2006". Version 2.31. FAO Fishery Information, Data and Statistics Unit.	*p. vannamei* 1990-99 natantian decapods nei 1984-86, 2005 spotted rose snapper/ pacific cupped oyster 2005 only
Cuba	Banco de Crédito y Comercio. 2006. El Cultivo de Camarón. "Serie histórica". Grupo Empresarial para el Desarollo del Cultivo de Camarón. Presentation, May 2006. 28p.	Production of prawn NBR 1986, 1991, 1996, 2000 - 2005
	Tamayo, R.J.M. 2006. Assessment of genetic variability in two lots of white shrimp, Litopenaeus vannamei (Boone, 1931) introduced to Cuba. Masters thesis. University of Tromsø, Norway.	Shrimp culture history, locations
	FAO. 2008. FishStat Plus: Universal software for fishery statistical time series. "Aquaculture production 1950 – 2006". Version 2.31. FAO Fishery Information, Data and Statistics Unit.	*P. schmitti* 1987-1990, 1992, 1994-96, 1998,99 *C. rhizophore* 1967-2005 Spiny lobster 1998-2004 *p.vannamei* 2004,05

Table A.1 Continued		
Primary References: Americas		
Country	**Source**	**Type of Information**
Dominican Republic	FAO. 2008. FishStat Plus: Universal software for fishery statistical time series. "Aquaculture production 1950 – 2006". Version 2.31. FAO Fishery Information, Data and Statistics Unit.	Penaeid shrimp 1985-1989 *c.virginica* 1991-93 snook 94-96 European seabass 2003-05 Gilthead bream 05 *Workstudy student noted fishstat data seemed unreliable*
	GEDSSP. 2005. Estudio del sector acuícola. Marco para el studio del Sector Acuícola en países Latinoamericanos: Républica Dominicana. Gestión Económica para el Desarrollo Sostenible del Sector Primario. Informe preliminary. 22p.	Penaeus shrimp 2000-04 Gilthead bream 03/04 *Data from SEMARN*
Ecuador	FAO. 2008. FishStat Plus: Universal software for fishery statistical time series. "Aquaculture production 1950 – 2006". Version 2.31. FAO Fishery Information, Data and Statistics Unit.	Production for all 4 species all years Red drum 99-2002 Scallops 87-01 *p. vannamei* 1969-2005 *p. stylirosis* 1973-2000 *– CNA production data in 'exports', no successful contacts, Workstudy student noted numbers that FAO have are questionable in their accuracy and completeness*
El Salvador	CENDEPESCA. 2001-2006. Estadisticas pesqueras y acuicolas. Vol 28-33. Ministerio de Agricultura y Ganaderia. Centro de Desarollo de la Pesca y Acuicultura, Unidad de Estadística e Informática, El Salvador.	*p. vannamei,* marine fishes 2001-06 (in kg)
	FAO. © 2006-2011. Visión general del sector acuícola nacional. El Salvador. National Aquaculture Sector Overview Fact Sheets. Text by Manuel F. Oliva. In: *Departamento de Pesca y Acuicultura de la FAO* [online]. Rome. Updated 1 February 2005. URL: www.fao.org/fishery/countrysector/naso_elsalvador/es. Accessed 31 January, 2007.	Industry history, species, environments, area (ha) of production pre species and region *–used for proportions,* production 'marine prawn' and 'marine fish' 2001-03, *data from CENDEPESCA*
	FAO. 2008. FishStat Plus: Universal software for fishery statistical time series. "Aquaculture production 1950 – 2006". Version 2.31. FAO Fishery Information, Data and Statistics Unit.	*p. vannamei* 1985-200 marine fishes 1985-2000 *Workstudy student noted early marine fish numbers likely capture fisheries, Blue shrimp-production should be assigned to p. vannamei instead*
Guam	SPC. 2002. Secretariat of the Pacific Community. SPC aquaculture portal - "Guam". URL: www.spc.int/aquaculture/site/countries/. Accessed May 8th, 2008.	Industry history, species cultured, production statistics for milkfish not included- *indication was not for human consumption*
	Bureau of Statistics and Plans. 2006. Guam Statistical Yearbook 2005. Release 4. Office of the Governor.	Marine shrimp, mullet, milkfish (not incl) 1992-1996
Guatemala	FAO. © 2006-2011. Visión general del sector acuícola nacional. Guatemala. National Aquaculture Sector Overview Fact Sheets. Text by López Paredes, **L.A.** In: *Departamento de Pesca y Acuicultura de la FAO* [online]. Rome. Updated 1 February 2005. URL: www.fao.org/fishery/countrysector/naso_guatemala/es. Accessed 29 January, 2007.	Industry history, species, general location of culture
	FAO. 2008. FishStat Plus: Universal software for fishery statistical time series. "Aquaculture production 1950 – 2006". Version 2.31. FAO Fishery Information, Data and Statistics Unit.	Penaeus shrimps 1984-2005 Sea Mussels 1994-2003

Table A.1 Continued

Primary References: Americas		
Country	**Source**	**Type of Information**
Guyana	FAO. 2008. FishStat Plus: Universal software for fishery statistical time series. "Aquaculture production 1950 – 2006". Version 2.31. FAO Fishery Information, Data and Statistics Unit.	Penaeus shrimps 1984-2006 *there is indication in further literature of low-tech finfish fattening in lagoons*
Honduras	Saint-Paul, U. 1992. Status of aquaculture in Latin America. J. Appl. Ichthyol. 8: 21 – 39.	Species cultured, some industry info
	Stanley, D., Alduvin, C. 2002. Science and Society in the Gulf of Fonseca- The Changing History of Mariculture in Honduras. Prepared for World Bank, NACA, WWF and FAO Consortium Program on Shrimp Farming and the Environment, Work in Progress for public discussion. 39 p.	General locations of most important farm sites
	Pratt, L., Quijandria, G. 1997. Industria del camarón en Honduras: Análisis de sostenibilidad. Centro Latinamericano para la Competitividad y el Desarrollo Sostenible (CLACDS). *Contains a compilation of data from:* USAID-ROCAP-CRC, 1992; Banco Central de Honduras, 1988-91, 93-95; ANDAN 1996	National production of shrimp 1980 – 1996, gives estimated % split for each species*, data used is an average of this data and fishstat*
	FAO. 2008. FishStat Plus: Universal software for fishery statistical time series. "Aquaculture production 1950 – 2006". Version 2.31. FAO Fishery Information, Data and Statistics Unit.	Penaeus production for 1974-80, 97-2005, *workstudy student notes fishstat numbers do not match national stats #s, thinks nat'l stats more likely*
Jamaica	NRCA. 1998. Mariculture - Draft policy and regulation. Natural Resources Conservation Authority. Coastal Zone Management Division. URL: www.nepa.gov.jm/policies/draft/mariculture.htm. Accessed 2007.	Location of oyster farming
	FAO. 2008. FishStat Plus: Universal software for fishery statistical time series. "Aquaculture production 1950 – 2006". Version 2.31. FAO Fishery Information, Data and Statistics Unit.	Mangrove oyster 1982-2001 *P.vannamei* 2002-06
Martinique	Dao, J-C. 2003. Aquaculture development of Red drum (*Sciaenops Ocellatus*) in Martinique and the French West Indies. Institut français de recherché pour l'exploration de la mer (IFREMER). Le Robert, Martinique. 74-85 pp.	Locations, status of sector
	FAO. 2008. FishStat Plus: Universal software for fishery statistical time series. "Aquaculture production 1950 – 2006". Version 2.31. FAO Fishery Information, Data and Statistics Unit.	Red drum, marine fish 1987-2005
Mexico	SAGARPA/CONAPESCA. 2001-2003. Annuario Estadístico de Acuacultura y Pesca. Volumen de la producción pesquera de acuacultura en peso vivo según litoral y entidad federativa. Comisión Nacional de Acuacultura y Pesca. 252 p.	Shrimp production 2001-03, oyster prod 2002, 03 by region
	Cruz-Torres, M.L. 2000. Pink gold rush: Shrimp aquaculture, sustainable development and the environment in Northwestern Mexico. Journal of Political Ecology. 7: 63-90	Shrimp production by region 1989 -97- *data from SEMARNAP*
	DeWalt, B.R., J.R. Ramírez Zavala, L. Noriega and R.E. González. 2002. Shrimp Aquaculture, the People and the Environment in Coastal Mexico. Report prepared under the World Bank, NACA, WWF and FAO Consortium Program on Shrimp Farming and the Environment. Work in Progress for Public Discussion. Published by the Consortium. 73 pages.	Shrimp production by region 1998, some historical info- *data from SEMARNAP*
	Torres, P.A., Martinez, C.R., Mendoza, A.O. 1999. Desarrollo de la acuacultura den Mexico y perspectivas de la acuacultura rural. Red de acuicultura rural en pequeña escala. Taller ARPE, FAO-UCT. 9 – 12 November 1999. 7 p.	NBR data from annual yearbooks for shrimp, oyster, other 1989 to 1998
	Phillips, S. 2006. Marine Aquaculture Issue Paper #2. Pacific States Marine Fisheries Commission. Portland. 13 p.	Bluefin tuna production 2004/05- *actual source Smart and Sylvia (2006), ref not in works cited of paper*
	FAO. 2008. FishStat Plus: Universal software for fishery statistical time series. "Aquaculture production 1950 – 2006". Version 2.31. FAO Fishery Information, Data and Statistics Unit.	Shrimp 1990,91,98-00,04,05, all years for remaining species *–workstudy student noted large discrepancy between yearbooks and fishstat, possibly because of oyster*

Table A.1 Continued		
Primary References: Americas		
Country	**Source**	**Type of Information**
Netherland Antilles	FAO. 2008. FishStat Plus: Universal software for fishery statistical time series. "Aquaculture production 1950 – 2006". Version 2.31. FAO Fishery Information, Data and Statistics Unit.	Stromboid conchs nei 1987-2001
Nicaragua	ADPESCA. 2001-2006. Anuario Pesquero y Acuicola de Nicaragua. Administración Nacional de Pesca y Acicultura. Ministerio de Fomento, Industria y Comercio (MIFIC). Managua. URL: www.mific.gob.ni	Shrimp production 1993-2004 NBR (in lbs) – *production #s back to 1989, don't match fishstat*
	FAO. © 2006-2011. Visión general del sector acuícola nacional. Nicaragua. National Aquaculture Sector Overview Fact Sheets. Text by Saborio Coze, A. *In:* Departamento de Pesca y Acuicultura de la FAO [online]. Rome. Updated 1 February 2005. URL: www.fao.org/fishery/countrysector/naso_nicaragua/es. Accessed January 1, 2007.	Industry history, species, location of culture
	FAO. 2008. FishStat Plus: Universal software for fishery statistical time series. "Aquaculture production 1950 – 2006". Version 2.31. FAO Fishery Information, Data and Statistics Unit.	Production for shrimp 1988-92,05
Panama	FAO. © 2006-2011. Visión general del sector acuícola nacional. Panamá. National Aquaculture Sector Overview Fact Sheets. Text by Pretto Malca, R. *In*: Departamento de Pesca y Acuicultura de la FAO [online]. Rome. Updated 1 February 2005. URL: www.fao.org/fishery/countrysector/naso_panama/es. Accessed January 29, 2007.	Industry history, species, location of culture (proportions derived by hectares given), production 2004 – *production data from Dirección Nacional de Acuicultura*
	Martínez, L., Gonzáles, S., Araúz, N.D., Bernal, O. 2005. Estadística pesquera comentada años 2000-2004. Dirección General de Recursos Marinos y Costeros. Autoridad Marítima de Panamá. 86 p.	Shrimp production 2000-04 NBR, proportions, *cultured amounts in some yearbooks save d to file different than fishstat*
	FAO. 2008. FishStat Plus: Universal software for fishery statistical time series. "Aquaculture production 1950 – 2006". Version 2.31. FAO Fishery Information, Data and Statistics Unit.	Blue shrimp 1977-1998 Whiteleg shrimp 1975-99, 2003,05
Peru	PRODUCE. 2007. Peru: Cosecha de la Actividad de Acuicultura marina Según Especie. Estadisticas de Pesca [online]. Viceministerio de Pesqueria. Dirección General de Acuicultura. URL: www.produce.gob.pe/produce/estadisticas/. Accessed November 23, 2007.	Scallop, prawn, pacific oyster 1997-2006 NBR *–concessions are identifiable by coordinates*
	Dirección Regional de la Produccion. 2005. Anuario estadistico 2004-2005. Peru: Cosecha de la Actividad de Acuicultura marina Según Especie.	Scallop, prawn, pacific oyster 2004 NBR, 2005 by region
	Pinillos, V.Y. 2000. Estado Situacional de la Mariculture en la Costa Peruana. Instituto del Mar del Peru. Chucuito Callao. 11 p.	Sector status, locations, species
	FAO. © 2006-2011. Visión general del sector acuícola nacional. Perú. National Aquaculture Sector Overview Fact Sheets. Text by Soto Cárdenas, G. I. *In*: Departamento de Pesca y Acuicultura de la FAO [online]. Rome. Updated 1 February 2005. URL: www.fao.org/fishery/countrysector/naso_peru/es. Accessed November 23, 2007.	Industry history, species, location of culture (proportions of total production), Scallop, prawn, pacific oyster NBR 2003
	FAO. 2008. FishStat Plus: Universal software for fishery statistical time series. "Aquaculture production 1950 – 2006". Version 2.31. FAO Fishery Information, Data and Statistics Unit.	Scallop, shrimp 1974-1996, - *indication that fishstat numbers for some sp. may not be reliable (ie. did not use oyster), only indicates whiteleg prawn but blue shrimp cultured too*
Puerto Rico	Brian Hanlon, 2006. Snapperfarms. Personal Communication [email].	Cobia production 2003/04
	McGee, M.V. Aquaculture presents new opportunities for Puerto Rican farmers. Caribe Fisheries Inc. Lajas. 5 p.	Shrimp farm location
	FAO. 2008. FishStat Plus: Universal software for fishery statistical time series. "Aquaculture production 1950 – 2006". Version 2.31. FAO Fishery Information, Data and Statistics Unit.	Mangrove cupped oyster 1996/97, shrimp 1996-05

Table A.1 Continued		
Primary References: Americas		
Country	**Source**	**Type of Information**
Suriname	FAO. © 2004-2011. Fishery and Aquaculture Country profiles. Suriname. Fishery and Aquaculture Country Profiles. In: *FAO Fisheries and Aquaculture Department* [online]. Rome. URL: www.fao.org/fishery/countrysector/FI-CP_SR/en. Accessed January 23, 2007.	Sector info, species, farm info
	FAO. 2008. FishStat Plus: Universal software for fishery statistical time series. "Aquaculture production 1950 – 2006". Version 2.31. FAO Fishery Information, Data and Statistics Unit.	*p. vannamei* 1998-2005 NBR
Turks and Caicos	Davis, M., Shawl, S. 2005. Queen conchs – Conservation through aquaculture, education. Global Aquaculture Advocate, August 2005. Global Aquaculture Alliance. p 58.	Information of queen conch, species, location
	FAO. 2008. FishStat Plus: Universal software for fishery statistical time series. "Aquaculture production 1950 – 2006". Version 2.31. FAO Fishery Information, Data and Statistics Unit.	Stromboid conchs, marine crabs 1987-2005
United States of America	**Alabama:**	Production of *c.virginica* estimated from national data
	Alaska: Alaska Department of Fish and Game. 2005. Alaska Aquatic Farm Production Summary 1990-2004.Mariculture Information Database. Alaska Department of Fish and Game. 2005. Table 3: Statewide aquatic farm sales, all species.	Clam, oyster, mussel production 1990-04 *Data provided by D.Petree (ADFG).* Breakdown of species cultured 2002/03
	California: California Department of Fish and Game.2005. State of California freshwater and marine aquaculture production. National Marine Fisheries Service - Southwest Regional Office. URL: http://swr.ucsd.edu/fmd/bill/aquaca.htm. Accessed August 13, 2005.	Abalone, mussel, oyster prod 1992-94
	Connecticut: Connecticut Department of Agriculture. 2005. Connecticut Oyster market harvest –Production statistics for Year 1990-2003. URL: www.ct.gov/doag/cwp/view.asp?a=1369&q=271358. Accessed August 13, 2005.	Hard clam and oyster prod in bushels 1990-2003
	Florida: United States Department of Agriculture. 2005. National Agricultural Statistics Service. URL: www.nass.usda.gov/fl/rtoc0a.htm. Accessed August 13, 2005.	Production of clam and oyster in Florida for odd years 1989 to 2003, 1987 to 1995 (converted from bushels - *Link no longer works*
	Hawaii: Wyban, J.A, Wyban, C.A. 1989. Aquaculture in Hawaii: past, present, and future. Advances in Tropical Aquaculture, Feb 20-March 4, 1989.AQUACOP, IFREMER, Actes de Colloque. 9: 37-43.	Prawn production 76-83 (*incl fw*)
	Louisiana:	Production of oysters and *m. mercenaria* estimated from unassigned national data
	Maine: Maine Department of Marine Resources. 2005. Marine finfish harvest 1988-2003. URL: www.maine.gov/dmr/aquaculture/lease_inventory_2004/finfish_harvest_chart_files/finfishharvestchart.htm. Accessed August 14, 2005. Maine Department of Marine Resources. 2005. Maine marine aquaculture harvest data. URL: www.maine.gov/dmr/aquaculture/HarvestData.htm. Accessed August 14, 2005	Atlantic salmon prod 88-03 Blue mussel 05-08 *In pounds*
	Maryland:	Production of oysters, sand gaper, soft crab, *m.mercenaria* estimated from national data/ unassigned nat'l data

Table A.1 Continued		
Primary References: Americas		
Country	**Source**	**Type of Information**
United States of America (cont'd)	**Mississippi:**	Production of *m. mercenaria* estimated from unassigned nat'l data
	New Jersey:	Production of *c.virginica*, *m.mercenaria* estimated from nat'l data/ unassigned nat'l data
	New York: Barnes, D., Rivara, G, Rivara, K. 2004. Shellfish aquaculture in New York State. *In:* Timmons, M. Rivara, G., Baker, D. Regenstein, J. Schreibman, M., Earner, P., Barnes, D., Rivara, K. 2004. New York aquaculture industry: Status, constraints and opportunities. A white paper. Department of Biological and Environmental Engineering, Cornell University. 43 p.	Hard clam production 1980,85,90,95-2001, (*converted from bushel*) includes bushel conversion fig
	North Carolina: North Carolina Department of Agriculture & Consumer Services. 2005. North Carolina aquaculture statistics.URL: www.ncagr.com/aquacult/sttable.html. Accessed August 13, 2005	Production of oyster and clam by bushel 2001/2002
	Oregon: Oregon Agricultural Statistics Service. 2003-2004. Table 120: "Oyster production: Pacific oysters harvested by estuary". Oregon, 1980-2003. Oregon Department of Agriculture and Oregon Department of Fish and Wildlife.	C. gigas prod 1980-93 (*converted from gallons*)
	Rhode Island: Alves, D. 2002. Aquaculture in Rhode Island. 2001 Yearly status report. Coastal Resources Management Council. Wakefield, RI. 21p.	Production (*by individs*) of clam and oyster 96-01, euro. oyster 01
	South Carolina:	production of *p. vannamei* and *m. mercenaria* estimated from unassigned national data
	Texas:	Production of *p.vannamei* estimated from national data
	Virginia: Murray, T.J., Kirkley, J.E. 2005. Economic activity associated with clam aquaculture in Virginia – 2004. VIMS Marine Resource Report No. 2005-5. 21p.	Clam production 04,03,01,00 Production of *c.virginica*, *soft crab* estimated from national data
	Washington: Puget Sound Action Team. 2003. Shellfish economy - Treasures of the Tidelands. URL: www.psat.wa.gov/Programs/shellfish/fact_sheets/economy_webl.pdf. Accessed August 15, 2005	2000 production estimate of shellfish by broad species, species cultured
	Western Region Aquaculture Center (WRAC). 2001. Western Region Aquaculture industry situation and outlook report. Part III: Aquaculture production from 1994 to present. Vol 6 (through 1999). Western Regional Aquaculture Center, University of Washington, WA. 28p.	prod of most major sp in **AK,WA,OR,CA** 94-99, scattered others, incl conversion figs
	National Marine Fisheries Service (NMFS). 2005. Estimated U.S. Aquaculture Production, 1983-1994 / 1994-1999 / 1997-2002. Fisheries Statistics Division. URL: www.st.nmfs.noaa.gov/st1/index.html Accessed August 15, 2005	1983-2002 estimated national production salmon, clam, mussel, oyster, shrimp
	FAO. 2008. FishStat Plus: Universal software for fishery statistical time series. "Aquaculture production 1950 – 2006". Version 2.31. FAO Fishery Information, Data and Statistics Unit.	About 50% of all species production data (by yr) 1950-2006 – *US data very difficult to disaggregate*

Table A.1 Continued		
Primary References: Americas		
Country	**Source**	**Type of Information**
Venezuela	Instituto Oceanográfico de Venezuela. 2008. Venezuela Acuicultura 1950-2005. Instituto Oceanográfico de Venezuela, Universidad de Oriente. Sucre. Data provided by César Lodeiros [email], January 2008.	Rock mussel, blue shrimp. Whiteleg 1984-2005 -*Data appears to be in the form sent to Fishstat, numbers match fishstat exactly. Official national stats report 'aquaculture'*
	FAO. 2005. Fishery Country Profile - Venezuela. URL: www.fao.org/fi/fcp/es/VEN/profile.htm. Accessed January 9th, 2008.	Sector history, marine shrimp 2003, locations, species
	Jory, D., Cabrera, T., Polanco, B., Sánchez, R., Millán, J., Rosas, J., Alceste, C., Garcia, E., Useche, M., Agudo, R. 2000. Aquaculture in Venezuela: perspectives. Aquaculture Magazine Sept/Oct 1999 25 (5): 4 p.	Sector history, locations, proportions, species

No Commercial Mariculture production as of 2004 in: Anguilla (UK), Antigua and Barbuda, Aruba, Barbados, Bermuda, British Virgin Islands (UK), Cayman Is. (UK), Dominica, French Guiana, Grenada, Guadeloupe (FR), Haiti, Montserrat (UK), St. Lucia, St. Kitts and Nevis, St. Pierre and Miquelon (FR), St. Vincent and the Grenadines, Trinidad and Tobago, Uruguay, US Virgin Islands

Table A.1 Continued		
Primary References: Asia		
Country	**Source**	**Type of Information**
Bahrain	Al-Radhi, A. 2006. Table of fish fry production at National Mariculture Centre for years 1993 – 2004. National Mariculture Centre. email communication.	Production by species, NBR, 1993 - 2004
Bangladesh	Government of Pakistan. 2010. Fisheries Statistics. Annexure-1. Ministry of Food, Agriculture and Livestock (MINFAL). URL: www.pakistan.gov.pk/divisions/food-division//media/minfal-01.pdf. Accessed January 12th, 2010.	National production 1996 – 2001, includes capture fisheries – assumed mariculture 0.015% of total, based on FAO Fishstat figures, table is cached
	Deb, A.K. 1998. Fake blue revolution: environmental and socio-economic impacts of shrimp culture in the coastal areas of Bangladesh. Ocean & Coastal Management 41: 63-88 pp.	Shrimp species name, rough regional map, 'shrimp' production 1983-96, *data from Bangladesh Department of Fishery*
	FAO. 2008. FishStat Plus: Universal software for fishery statistical time series. "Aquaculture production 1950 – 2006". Version 2.31. FAO Fishery Information, Data and Statistics Unit.	National production of 'Penaeus shrimps nei 1950-1983
	Alauddin, M. & Hamid, M.K. 1999. Shrimp culture in Bangladesh with emphasis on social and economic aspects. Paper presented at the workshop: "Towards Sustainable Shrimp Culture in Thailand and the Region", Hat Yai, Songkhla, Thailand, 28 October - 1 November 1996. Workshop proceedings published by ACIAR (Australian Center International Agricultural Research), No.90, 1999.	Proportions of shrimp species produced
	BBS. 2004. Statistical Yearbook of Bangladesh 2002. Bangladesh Bureau of Statistics, Planning Division. Ministry of Planning. Government of the People's Republic of Bangladesh. 744 p.	Coastal shrimp farm 'culture', NBR, 03/04
	DOF. 2005. National Fish Fortnight. Department of Fisheries, Ministry of Fisheries and Livestock. Government of the People's Republic of Bangladesh. 87 p.	Shrimp farm 'catch', by region 1998/99, 99/00 NBR, 2000
Brunei	The Government of Brunei Darussalam. Potential fisheries investment Areas – Aquaculture. Fisheries Department. URL: www.fisheries.gov.bn/potentials/aquaculture.htm. Accessed October 27th, 2006.	Approx. aquaculture site locations
	UT. 2009. Asia Maps – "Brunei". Perry-Castañeda Library Map Collection [online]. University of Texas, Austin. URL: http://www.lib.utexas.edu/maps/. Accessed January 27, 2011	Brunei administrative regions
	Hamid, H.L.H. 2005. Current status of transboundary fish diseases in Brunei Darussalam: Occurrence, surveillance, research and training. Deparment of Fisheries. *In*: Southeast Asian Fisheries Development Centre (SEAFDEC). 2004. Meeting on Current status of transboundary fish diseases in Southeast Asia: Occurrence, surveillance, research and training. Government of Japan Trust Fund Regional Fish Disease Project. 23 -24 June, 2004, Manila. URL: http://rfdp.seafdec.org.ph/meetings/manila-meetransb/report-brunei.html. Accessed October 27th, 2006.	Production of *p.monodon* and *l. stylirostris* 1999 – 2003, *sourced from SEAFDEC Aquaculture Research Division (AQRD), regions interpolated*
	FAO. 2008. FishStat Plus: Universal software for fishery statistical time series. "Aquaculture production 1950 – 2006". Version 2.31. FAO Fishery Information, Data and Statistics Unit.	Barramundi 1987-2004 Tiger prawn 2004, 1998-1992 Marine fish 2003-1993 Swamp crab / Grouper / Blue shrimp 2004 Jacks etc 2004-1993 Snappers 2004 - 1993

Table A.1 Continued

Primary References: Asia

Country	Source	Type of Information
	Department of Fisheries (DOF). 2001. Aquaculture Review. Agriculture Productivity Improvement Project (APIP). The Fisheries Component. Technical Paper No. 4. 42p.	History of industry, % of aquaculture in total production, 1984, 1990, 1998, % FW in total aquaculture, % for major region, "coastal aquaculture" by region 1984 – 1998, by region, 'shrimp' and 'fish' 1988 - 1998, *culture by sp. and region inferred based on known %marine culture, # species, # provs producing*
	Ministry of Agriculture, Forestry and Fisheries. 2006. Statistics of Fisheries – Table of Status of Fisheries Production. URL: www.maff.gov.kh/statistics/fishstat.html. Accessed April 8th, 2006.	Aquaculture of "fish" 1980 – 2004, *marine culture inferred based on known %marine culture, # species, # provs producing*
China	**Hong Kong SAR:** Agriculture, Fisheries and Conservation Department (AFCD). 2006. Data provided by Mr. Rock KY Kwok. FAO. 1991. Regional seafarming resources atlas: Volume II. "Hong Kong". Regional Seafarming Development and Demonstration Project. National Inland Fisheries Institute. Bangkok. 15 p. URL: www.fao.org/docrep/field/003/AB732E/AB732E05.htm. Accessed November 23rd, 2006.	Mariculture production of fish, pacific oyster 1975-2005, areas of culture Species cultured, % comp. of fish species
	China Main: **1.** Jiwu, Z., Rørveit, J. 2004. Aquaculture in China. Innovation Norway, Beijing. 49 p.	% of production for some species and years, production of broad categories 1978, 2003, some regional info 2003, marine finfish by province 2003 – *data sourced by China Fishery Statistic Yearbook*
	2. ANON. 2005. Anonymous Government Source. Marine production and area by major species group and province 2000 – 2005. Unpublished Data. Translated by Dr. William Cheung.	Production of major species groups by province 2000 – 2005, *interpolation of individual sp by % from other literature*
	3. Chinese Academy of Fishery Sciences (CAFS). 2006. Database of marine aquaculture production. Compiled and translated by Dr. Yajie Liu. URL: http://www.cafs.ac.cn/page/cafs/yuyetongji/main.asp. Accessed November 2006.	Production by province and both broad and individual species categories 1996 -2001
	4. Bureau of Fisheries. 2006. People's Republic of China Mariculture production by major species 1999. Ministry of Agriculture, Distant Water Fishery Development and Research Centre. URL: http://prfisheries.alaskapacific.edu/PRF_Statistics/china/MaricultureBySpecies.htm. Accessed November 2nd, 2006.	Production of major species by province 1999, 2003
	5. NOAA .2006. China Fishery Statistics. National Oceanographic Data Center. Aquaculture Information Centre [online]. URL: www.lib.noaa.gov/china/archi/statistics.htm#marine_cul_prod. Accessed February 11, 2006.	China Stats by major sp. NBR 1978-1992 – *site now retired as of 2011*
	6. NOAA. 2007. China - Aquaculture industry. National Oceanographic Data Center [online]. URL: www.lib.noaa.gov/china/aquaculture.htm. Accessed November 1, 2007.	Mariculture production total by region 1954,55,65,75,85,90,95,97
	7. FAO. 2008. FishStat Plus: Universal software for fishery statistical time series. "Aquaculture production 1950 – 2006". Version 2.31. FAO Fishery Information, Data and Statistics Unit.	Production of select species and years 1998--1950 *1994-1998: estimated ~ 9% of annual total prod is fishstat, 1993: 2%, 1983-1992: 0%, 1982-79 70%, 1978: 5%, 1950-1977: 100%* Primarily proportional estimation prior to 1969

Table A.1 Continued		
Primary References: Asia		
Country	**Source**	**Type of Information**
China (cont'd)	**8.** Rana, K., Perotti, M., Montanaro, S., Immink, A. 1998. Aquaculture Production in China. FAO Aquaculture Newsletter – December 1998. No. 20. FAO Fisheries Information, Data and Statistics Unit. URL: www.fao.org/docrep/005/x1227e/X1227e9.htm. Accessed January 29, 2007	Conversion rates used by Chinese Min Ag for Japanese carpet shell, Pacific cup oyster, misc. mollusk, discussion of shucked/unshucked weight issue
	9. Zhiwen, S. 1997. A Review of Aquaculture Extension Services in the People's Republic of China. RAP Publication 1997/34. FAO Regional Office for Asia and the Pacific, Bangkok. URL: www.fao.org/DOCREP/005/AC804E/ac804e07.htm. Accessed October 27, 2006.	Mariculture prod by major species NBR 1983 -1991
	10. Jia, J., Chen, J. Sea Farming and Sea Ranching in China. 2001. FAO Fisheries Technical Paper 418. FAO, Rome. 75 p. URL: www.fao.org/docrep/005/Y2257E/Y2257E00.htm. Accessed November 17, 2006.	Species info, marine farming/ranching NBR, NBsp 1950-1999, sea farming NBR, broad sp. 1996-99, list of species cultured (English and Chinese characters) 1978, 1983 bivalve, shrimp by sp. NBR 1970-1983 mussel NBR 1979-1983 chinese shrimp NBR
	11. FAO. 1988. Status of mollusk culture in selected Asian countries. Project Reports. Network of Aquaculture Centres in Asia. National Inland Fisheries Institute, Bangkok. URL: www.fao.org/docrep/field/003/AB718E/AB718E02.htm. Accessed December 19, 2006.	Bivalve percent production breakdown by major species Bivalve species production NBR 1980-1986
	12. Jian-guang, F., Qisheng, T. 2005. Development of mussel industry in China. PowerPoint Presentation. Yellow Sea Fisheries Research Institute.	Production of main bivalve species 2004, info on mussel culture incl. distribution and species
	13. Ministry of Agriculture of the People's Republic of China. 2004. Table-"Quantity (ton) Aquaculture Product 2004". Information Centre [online] URL: www.agri.gov.cn/sjel/2004/213.htm. Accessed November 7, 2006.	Mariculture by province 2004, NBsp. *In Chinese*
	14. Guo, X. 2000. Aquaculture in China: two decades of rapid growth. Aquaculture Magazine. May/ June 2000 26(3). URL: www.aquaculturemag.com/siteenglish/printed/archives/issues00/300a.htm. Accessed November 7, 2006.	Industry info, history, species info, locations of culture, species production NBR 1998
	For additional articles with small amounts of 'data on individual species' see hardcopy folders	
East Timor	**See Indonesia-***data in Indonesian yearbooks*	*Also known as Timor-Leste* Misc fish, *chanos chanos, p. monodon*, mullet, 1986-1997 (dataset complete?-war)
India	Anonymous, 2001. Status of Indian shrimp aquaculture: overview. *Fishing* chimes, 21(6), 27-32	*Information and references compiled by Brajgeet Bhathal, more specific notes for references in Aqua_Braj.xls tables - There is an indication that finfish culture occurs but no #s*
	Anonymous, 2001. Shrimp aquaculture- Global and Indian scenarion. *In:* Shrimp aquaculture & the environment-an environment impact assessment report. Aquaculture authority, Chennai, India. pp. 10-41	
	Anonymous. 2003. Status of shrimp farming in Andhra Pradesh. *Aquaculture Authority News,*1(3), 8-11.	
	DAHD, 2001. Handbook on fisheries statistics 2000. Ministry of Agriculture, New Delhi. pp 128. DAHD, 2005. Handbook on fisheries statistics 2004. Ministry of Agriculture, New Delhi. pp 58.	
	Indiastat. 2006. URL: www.Indiastat.com. Accessed October 2006.	Data for year 1995 only

Table A.1 Continued		
Primary References: Asia		
Country	**Source**	**Type of Information**
India (cont'd)	M. Devaraj and K. K. Appukuttan, 2000. Perspective on coastal aquaculture in India. V.N. Pillai and N. G. Menon (Eds.) *In*: Marine fisheries research and management. Central Marine Fisheries Research Institute, Kochi, India. pp 677-687.	
	N. G. K Pillai, Mohan Joseph Modayil and U. Ganga, 2003. Marine fishing practices and coastal aquaculture technologies in India. *In:* Anjani Kumar, Pradeep K Katiha and P K Joshi (Eds.) A profile of people, technologies and policies in fisheries sector in India; Proceedings series # 10. National Centre for Agricultural Economics & Policy Research, New Delhi, India, pp.83-122	
	N. G. K. Pillai and Pradeep K Katiha, 2004. Profile of Inland aquaculture and fisheries technology. Mohan Joseph Modayil (Ed.) *In*: Evolution of fisheries and aquaculture in India. Central Marine Fisheries Research Institute, Kochi, India. pp 43-96.	
	N. G. K. Pillai and Pradeep K Katiha, 2004. Profile of aquaculture and fisheries technology. Mruthyunjaya (Ed.) *In:* Strategies and options for increasing and sustaining fisheries and aquaculture production to benefit poor households in India. National Centre for Agricultural Econmics and Policy Research, New Delhi, India. pp. 11-34	
	G. Sanathanankrishnan, 1999. Indian shrimp culture scenario. 12th Indian Seafood Trade Fair Souvenir. Seafood Exporters Association of India, Kochi, pp. 13-21	
Indonesia	IBS. 2004. Yearbook Perikanan Budidaya/Aquaculture. Table: Number of marine culture households, area culture and production by species and province. Indonesian Bureau of Statistics (Badan Pusat Statistik). Jakarta. Directorate Jenderal Perikanan. 1972 -1999. Statistik Perikanan 1972 (*Fisheries Statistics of Indonesia 1972*). Laporan No 3. Deparetemen Peritanian. Jakarta. Select pages. Directorate Jenderal Perikanan Budidaya. 2001-2004. Statistik Perikanan Budidaya Indonesia (*Indonesian Aquaculture Statistics 1999*). Laporan No 3. Deparetemen Kelautan dan Peritanian. Jakarta. 127 p.	*data from Dr. J. Alder* ***– including Timor-Leste*** Production by major species (13) and region 1999, 2003 – *in Indonesian* 2004 estimated Production by major species and region 1994 - 2003 Production by region, species 1972-99, 1999-2003 *–for a complete list of references see hardcopy references*
Iran	FAO. 2008. FishStat Plus: Universal software for fishery statistical time series. "Aquaculture production 1950 – 2006". Version 2.31. FAO Fishery Information, Data and Statistics Unit.	*p. indicus* 1991 – 2004 **,** *literature indicates p.semisulcatus also farmed, no data*
	FAO. © 2006-2010. National Aquaculture Sector Overview. Iran (Islamic Republic of). National Aquaculture Sector Overview Fact Sheets. Text by Abdolhay, H**.** In: *FAO Fisheries and Aquaculture Department* [online]. Rome. Updated 1 January 2005. [Cited 15 Nov 2006]. http://www.fao.org/fishery/countrysector/naso_iran/en	Sector overview, species cultured, locations of culture
Israel	FAO. 2008. FishStat Plus: Universal software for fishery statistical time series. "Aquaculture production 1950 – 2006". Version 2.31. FAO Fishery Information, Data and Statistics Unit.	All production by species 1984 - 2004
	Gordin, H. 1999. Mariculture developments in Israel: Present and future. National Center for Mariculture (NCM). Ministry of Agriculture and Rural Development. P. 69-71. Workshop of the CIHEAM Network on Socio-economic and Legal Aspects of Aquaculture in the Mediterranean (SELAM), Tangiers (Morocco), 12-14 Mar 1998. URL: http://ressources.ciheam.org/om/pdf/c43/99600258.pdf. Accessed November 10, 2006.	Industry history, regions of culture, species, broad production #s
	Gordin, H. 2003. Mariculture in Israel. The Israeli Journal of Aquaculture – Bamidgeh. 55(4):219 – 221.	Industry history, regions of culture, species

Table A.1 Continued

Primary References: Asia		
Country	**Source**	**Type of Information**
Japan	Ministry of Agriculture and Forestry. 2006. The 81st statistical yearbook of Ministry of Agriculture and Forestry Japan. Statistics Department. Select pages. Ministry of Agriculture and Forestry. 1956-2002. "Marine culture". The Nth statistical yearbook of Ministry of Agriculture and Forestry. Fisheries Statistics Section, Statistics and Survey Division. Select pages.	Production in *kan* (= 3.75kg), for major species, by prefecture 1956 -60, 63, 69,73-2002, 2005 *-Missing yrs interpolated (50-52, 61, 62, 65-68, 70-72, 03, 04), some additional proportional allocation to region, yrbks from UBC asian library* *-could further disaggregate data*
	Ministry of Agriculture, Forestry and Fisheries. 2010. Historical Statistics of Japan. Chapter 7: Agriculture, Forestry and Fisheries. Statistics Department, Minister's Secretariat. URL: www.stat.go.jp/english/data/chouki/07.htm. Accessed March 30, 2010.	National production of major species 2003-1956
	Ministry of Agriculture, Forestry and Fisheries. 2007. Gyogyo Yoshokugyo Seisann Tokei Nenpo. Yoshokugyo Gyoshubetu Shukakuyo Ruinen. URL: www.e-stat.go.jp/SG1/estat/List.do?lid=000001061498. Accessed March 30, 2010.	National production of major species 2005-1956 *Translation assistance from Wilf Swartz*
	FAO. 2008. FishStat Plus: Universal software for fishery statistical time series. "Aquaculture production 1950 – 2006". Version 2.31. FAO Fishery Information, Data and Statistics Unit.	Yellowtail 1964-50 Oyster 1955-50 Misc Fish 1969-65
Korea, Dem. Rep.	UT. 2009. Asia Maps – "Korea Maps". Perry-Castañeda Library Map Collection [online]. University of Texas, Austin. URL: www.lib.utexas.edu/maps/. Accessed January 27, 2011	Map of administrative regions
	FAO. 2008. FishStat Plus: Universal software for fishery statistical time series. "Aquaculture production 1950 – 2006". Version 2.31. FAO Fishery Information, Data and Statistics Unit.	Marine mollusks nei 1975-2004 *-very data poor country* *-other literature indicates production of shrimp, sea cuke, clam, abalone, mussel, urchin, 'saltwater fishes', no data available*
Korea, Rep.	1. Fisheries Department of the Republic of Korea. 1962-1977. Susan t'onggye yonbo: Yearbook of fisheries statistics. Taehan Min'guk Susanch'ong. Select pages.	Culture by species by region 1961-1976, excl 66,69,71 *yrbks from UBC Asian library*
	2. Korea National Statistical Office. 2006. Amount of catch by fishery type and species. Korea National Statistical Office: Searchable database (KOSIS). URL: www.hso.go.kr/eng/searchable/kosis-list.html. Accessed June 2006.	Production by broad taxon 2003 – 1978, *most sp by region is interpolation >1977*
	3. Ministry of Maritime Affairs and Fisheries (MOMAF). 2006. Production by Province (2004). Statistical Yearbook of Maritime Affairs and Fisheries. MOMAF Statistics. URL: www.momaf.go.kr/eng/fish/stat/F_stat_view.asp?idx=18&RNUM=7. Accessed June 27th, 2006.	Shallow-sea production by broad taxon 2004- 1999 (*matches KOSIS*), 2004 'shallow sea culture' by province not by species **NOTE**: ministry has changed names as of 2011 to http://english.mltm.go.kr/intro.do
	4. Fishery Resources Bureau. 1999-2004. Yearbook of fisheries statistics. "Status of shallow-sea culture".	Total shallow-sea production by species 1998-2003 *Downloaded (from MOMAF?)*
	5. Bai, S.C. 2005. Marine farming country analysis – Republic of Korea. Department of Aquaculture/Feeds and foods Nutrition Research Centre (FFNRC).	shellfish and finfish major species 2003 – *data from Fisheries Assoc. of Korea*
	6. FAO. 1990 Seafarming production statistics from China, Hong Kong, India, Indonesia, Malaysia, Pakistan, Philippines, Korea (Rep.), Singapore and Thailand. UNDP/FAO Regional Seafarming Development and Demonstration Project. National Inland Fisheries Institute. Bangkok. URL: www.fao.org/docrep/field/003/AB735E/AB735E00.htm#TOC. Accessed April 16, 2006.	Prod by major finfish, mollusk, crustacean sp 1985-1989, *#s way higher than KOSIS*

Table A.1 Continued

Primary References: Asia

Country	Source	Type of Information
Korea, Rep. (cont'd)	**7.** NOAA. 2006. Korea-US Aquaculture. History / Main Species. National Oceanographic Data Center [online].URL: www.lib.noaa.gov/korea/main_species/ark.htm. Accessed June 22nd, 2006.	History of aquaculture, Black sea bream by province 1996-2000 Olive flounder by province 2001, bar graph from KNSO 1988-2001 Ark shell 1970,80,90,95,98,99 by region, all finfish proportions 2001
	8. FAO. 2008. FishStat Plus: Universal software for fishery statistical time series. "Aquaculture production 1950 – 2006". Version 2.31. FAO Fishery Information, Data and Statistics Unit.	Yellowtail 1980-97 Fleshy prawn 1972-2004 Olive flounder
Kuwait	FAO. 2008. FishStat Plus: Universal software for fishery statistical time series. "Aquaculture production 1950 – 2006". Version 2.31. FAO Fishery Information, Data and Statistics Unit.	All production by species 1987- 2004, orange-spotted grouper, marine fishes, gilthead bream, goldsilk bream, sobaity bream – *fishstat data appears to be significantly underreported*
	FAO. © 2006-2010. National Aquaculture Sector Overview. Kuwait. National Aquaculture Sector Overview Fact Sheets. Text by Murad, H.A**.** In: *FAO Fisheries and Aquaculture Department* [online]. Rome. Updated 21 March 2006. URL: www.fao.org/fishery/countrysector/naso_kuwait/en Accessed March 10, 2006.	Sector overview, species cultured, locations of culture
Lebanon	Ministère de l'Agriculture. 2004. Enquête production. "Productions Animales". *Production de poisson*. Direction des Etudes et de Coordination. FAO project "Assistance au recensement agricole" URL: www.agriculture.gov.lb/production99/annee_ani.htm. Accessed 14 June, 2010.	Production of 'aquaculture' 1997 – 2003
	FAO. © 2007-2010. National Aquaculture Sector Overview. Lebanon. National Aquaculture Sector Overview Fact Sheets. Text by Ibrahim A.H. In: *FAO Fisheries and Aquaculture Department* [online]. Rome. Updated 3 January 2005. URL: www.fao.org/fishery/countrysector/naso_lebanon/. Accessed March 10, 2006.	Sector overview, species cultured, proportions, locations of culture
	UT. 2009. Middle East Maps – "Lebanon". Perry-Castañeda Library Map Collection [online]. University of Texas, Austin. URL: www.lib.utexas.edu/maps/. Accessed January 27, 2011	Administrative regions
Malaysia	Department of Fisheries Malaysia (DOF). 2010. Annual fisheries statistics 1982 -2004. Vol 1. URL: www.dof.gov.my/59. Accessed Feb 16th, 2010.	Production by species and state 2004-1982 (yrbks prior do not distinguish aquaculture from capture)
	Biusing, R. 2001. Assessment of coastal fisheries in the Malaysian Sabah portion of the Sulu Sulawesi Marine Ecoregion (SSME). WWF Report.	Some taxon names
	FAO. 2008. FishStat Plus: Universal software for fishery statistical time series. "Aquaculture production 1950 – 2006". Version 2.31. FAO Fishery Information, Data and Statistics Unit.	Production blood cockle 1950-1983, tiger prawn 1973-83, Mangrove red snapper 1978-83, greasy grouper 1980-83, banana prawn 1982/83 NBR
Myanmar	SEAFDEC. 2003. Current Status of Viral Diseases in the Production of Shrimps and Prawn. Aquaculture Extension Manual. Southeast Asian Fisheries Development Center. URL: http://rfdp.seafdec.org.ph/publication/manual/trans/papers2.html. Accessed June 21, 2006.	Production of tiger prawn 1999-2003, NBR
	FAO. 1991. Myanmar. Regional Seafarming Resources Atlas. Vol. II. Regional Seafarming Development and Demonstration Project. National Inland Fisheries Institute. Bangkok. URL: www.fao.org/docrep/field/003/ab732e/AB732E00.htm#TOC. Accessed June 21, 2006.	Industry history, species info, general locations, oyster, tiger prawn
	FAO. 2003. Myanmar aquaculture and inland fisheries. Myanmar-Mission Report of Coastal Aquaculture. RAP Publication. Bangkok. 55 p.	1994-98, 2000 NBR marine shrimp, oyster shell, pearl, some locations, species info – *data from DOF and Winn Latt*
	FAO. 2008. FishStat Plus: Universal software for fishery statistical time series. "Aquaculture production 1950 – 2006". Version 2.31. FAO Fishery Information, Data and Statistics Unit.	Giant tiger prawn 1989-2004 NBR– *FAO #s and DOF #s similar for some years, very different for others*

Table A.1 Continued		
Primary References: Asia		
Country	**Source**	**Type of Information**
Oman	FAO. © 2006-2010. National Aquaculture Sector Overview. Oman. National Aquaculture Sector Overview Fact Sheets. Text by Al- Yahyai, D.S. In: *FAO Fisheries and Aquaculture Department* [online]. Rome. Updated 7 March 2006. URL: www.fao.org/fishery/countrysector/naso_oman/en. Accessed March 25, 2010.	Sector information, species cultured, locations.
	Chamber Oman. 2006. Quriyat Aquaculture Co. LLC. ASMAK. URL: www.chamberoman.com/member/qaqua/. Accessed May 29, 2006.	Sector information, locations
	Oman Economic Review. 2002. Fishing for good. July 2002. URL: www.oeronline.com/php/2002_july/main1.php. Accessed March 19th, 2010	Some production #s 2000, for some shrimp species in some regions
	UT. 2009. Middle East Maps – "Oman". Perry-Castañeda Library Map Collection [online]. University of Texas, Austin. URL: www.lib.utexas.edu/maps/. Accessed June 29, 2006	Administrative regions
	FAO. 2008. FishStat Plus: Universal software for fishery statistical time series. "Aquaculture production 1950 – 2006". Version 2.31. FAO Fishery Information, Data and Statistics Unit.	Production 1998 – 2004 NBR, *some interpolation of missing– oman does/did not report to FAO? Not confident fishstat accurately represents production*
Pakistan	FAO. 2008. FishStat Plus: Universal software for fishery statistical time series. "Aquaculture production 1950 – 2006". Version 2.31. FAO Fishery Information, Data and Statistics Unit.	Marine crustaceans 1988-2004 – *numbers unreliable? used as base # for division to species*
	MFAL. 2007. The Status of Fisheries and Aquaculture in Pakistan. Part 1. Ministry of Food, Agriculture and Livestock. Islamabad. 21 p.	Overview of sector, statement that there exists no farm registry or inventory system.
Philippines	Bureau of Agricultural Statistics. 2006. PIDS Agricultural Statistics tables. "Volume of production of species, Philippines by region". URL: http://dirp.pids.gov.ph/%7Esspn/. Accessed May 6th, 2006.	Production of major species by region 1979-1994, no data in 1992, *interpolation for 92, 95,96*
	Bureau of Agricultural Statistics. 2004. Fisheries Statistics of the Philippines 2001-2003. 91p. Bureau of Agricultural Statistics. 2002. Fisheries Statistics of the Philippines 1997-2001.	Production by major species and region 2001-2003 Production by major species and region 1997-2001
	Bureau of Fisheries and Aquatic Resources (BFAR). 2004. Philippines fisheries profile, 2004. 64 p.	Production of major species by region 2004
	FAO. 2008. FishStat Plus: Universal software for fishery statistical time series. "Aquaculture production 1950 – 2006". Version 2.31. FAO Fishery Information, Data and Statistics Unit.	Milkfish 1950-1978 NBR
Qatar	FAO. 2008. FishStat Plus: Universal software for fishery statistical time series. "Aquaculture production 1950 – 2006". Version 2.31. FAO Fishery Information, Data and Statistics Unit.	Production white-spotted spinefoot, yellowfin seabream 1996 -2004 NBR
Russia	Hansen, E., Muran, M. 2005. Russian Federation Fishery Products Annual 2005. GAIN Report. No RS5068. USDA Foreign Agriculture Service. 17 p.	Some sector info, some species and locations
	PICES. 2005. Russian national report on "Current status of research and problems of invertebrate mariculture in the Russian Far East". North Pacific Marine Science Organization. Report of the Working Group 18 on Mariculture. *In*: Mariculture in the 21st Century- The intersection between ecology, socio-economics and production. October 1, 2005. Endnote 3. URL: www.pices.int/publications/annual_reports/Ann_Rpt_05/2005%20WG18.pdf . Accessed 2007.	Some regions and species
	European Commission. 2009. EUROSTAT Data Explorer [online]. Fisheries – Aquaculture Production. V2.2.B.9. URL: http://epp.eurostat.ec.europa.eu/portal/page/portal/statistics/search_database. Accessed November 17, 2009.	Sea trout 1988-2004, Atl. Salmon 1999, 2004,05 NBR *(Atl. Salmon not listed in fishstat)* Mullet 1988-1996 Sea mussel 1988-2004 *-indication in the literature that pink salmon may also be cultured*

Table A.1 Continued

Primary References: Asia

Country	Source	Type of Information
Russia (cont'd)	FAO. 2008. FishStat Plus: Universal software for fishery statistical time series. "Aquaculture production 1950 – 2006". Version 2.31. FAO Fishery Information, Data and Statistics Unit.	Mediterranean mussel 1991-2000 Yesso scallop 1988-2004 NBR
Saudi Arabia	Ministry of Agriculture and Water. 2006. Fish and shrimps catch and production of fish farms (in ton) during 1994 – 2005.URL: www.agrwat.gov.sa/. Accessed March 10 2006.	Total production in "salty water" 1994 - 2005(link broken as of 2010)
	FAO. 2008. FishStat Plus: Universal software for fishery statistical time series. "Aquaculture production 1950 – 2006". Version 2.31. FAO Fishery Information, Data and Statistics Unit.	Barramundi, Flathead mullet, Goldlined seabream, White prawn, Rabbitfish, Tiger prawn, Groupers NBR 1986 -2004
	Ming-Hsien, L. YR. ICDF Aquaculture development in the Kingdom of Saudi Arabia. International Cooperation and Development. P 21-24. URL: www.icdf.org.tw/web_pub/20020702140316aquasaudi.pdf. Accessed March 2, 2006.	Sector history, some locations, sp produced, "saltwater aquaculture" production even yrs 1988-98
Singapore	Sien, C.1992.Singapore's urban coastal area: Strategies for management. Chapter 4 – Coastal resources use. ICLARM. P 60-62.	some industry history, locations, species cultured
	Chou, R., Lee, H.B. 1997. Commercial marine fish farming in Singapore. Aquaculture Research. 28:767 - 776	some industry history, locations, species cultured (Latin names), some proportions
	FAO. 2008. FishStat Plus: Universal software for fishery statistical time series. "Aquaculture production 1950 – 2006". Version 2.31. FAO Fishery Information, Data and Statistics Unit.	Gov't enquiry email referred to FAO database as official stats, *100% production is FAO, production by region is estimated*
Sri Lanka	De Silva, P., Khoa, S.N. 2007. Statistics of Aquaculture in Sri Lanka. Draft Report. International Water Management Institute (IWMI), Colombo. 20 p. De Silva, P., Khoa, S.N. 2007. Statistics of Aquaculture in Sri Lanka. Data Search- Phase 2 for the University of British Columbia. International Water Management Institute (IWMI), Colombo. 50 p.	Industry status, locations, all aquaculture and inland by province, culture of species by province 2006, bivalve production select years (***not entered***) detailed information on statistical collection process – *stats by and large inaccurate* Prawn production 1997-2004 *Sources compiled from NAQDA, NARA, MOF*
	MFAR. 2005. Map – Resources for Inland Fisheries and Aquaculture Development. Ministry of Fisheries and Aquatic Resources. Colombo. URL: www.fisheries.gov.lk/maps/ . Accessed November 10, 2008.	Map of shrimp farming areas
	Ministry of Fisheries and Aquatic Resources. 2006. Table - Aquaculture Production in Sri Lanka. URL: www.statistics.gov.lk/fishery/index.htm. Accessed November 10, 2006.	Crab and shrimp production NBR 1996-2005
	Angell, C.L.1998. Coastal Aquaculture zoning in Sri Lanka. Aquaculture Development. FAO Technical Cooperation Programme. 29 p.	Species overview, locations, production status
	FAO. 2008. FishStat Plus: Universal software for fishery statistical time series. "Aquaculture production 1950 – 2006". Version 2.31. FAO Fishery Information, Data and Statistics Unit.	Giant tiger prawn, 1978-1996 Crab 2002-04 (also as proportions)
Taiwan	Taiwan Fisheries Bureau. 1993-2007. 1993-2007 Fisheries Yearbook [online]. Department of Agriculture and Forestry, Provincial Government of Taiwan. Republic of China. URL: www.fa.gov.tw/eng/statistics/yearbooks.php. Accessed Jan 20th, 2010	All data 1993 -2007 on species produced, quantities, and districts**,** total prod by production type (NBR/NBS) back to 1954 –no tables of prod by sp and district *all subnational data are interpolated (see xls worksheet) indication that official numbers are inaccurate*
	Liao, I.C., Huang, T-S., Tsai, W-S., Hsueh, C-M., Chang, S-L., Leaño. 2004. Cobia culture in Taiwan: current status and problems. Aquaculture. 237: 157-165	History of cobia culture in Taiwan, culture #s NBR 1999-2002
	Yeh, S-P. 2000. The aquaculture status and its sustainability in Taiwan [online]. Department of Aquaculture. National Pingtung University of Science and Technology. URL: http://aquafind.com/articles/taiwan.php. Accessed February 21, 2010.	List of species cultured with taxon names

Table A.1 Continued		
Primary References: Asia		
Country	**Source**	**Type of Information**
Taiwan (cont'd)	UT. 2009. Asia Maps – "Taiwan". Perry-Castañeda Library Map Collection [online]. University of Texas, Austin. URL: www.lib.utexas.edu/maps/. Accessed June 29, 2006	Administrative regions
Thailand	Ministry of Agriculture and Cooperatives. 1989-2002. Fisheries Statistics of Thailand 1989. No. 2532 -2545. Department of Fisheries, Fisheries Statistics sub-Division. Ministry of Agriculture and Cooperatives. 1978-1984. The Marine Fisheries Statistics 1978 base on the sample survey. 1978: No. 6/1981; 1979: No. 9/1982; 1980: No. 2/1983; 1981: No. 2/1984; 1982: No. 2/1985; 1983: No. 2/1986; 1984: No. 13/1986. Department of Fisheries, Fisheries Economics and Planning sub-Division.	Production by province and species 1989-95, 97-2002 Production by province and species from yearbooks 1973-1984, *some proportional allocation for provs missing in reports (<5%)* Missing prod reports for 85-88,96, 03,04 –*production interpolated based on existing data*
United Arab Emirates	FAO. 2008. FishStat Plus: Universal software for fishery statistical time series. "Aquaculture production 1950 – 2006". Version 2.31. FAO Fishery Information, Data and Statistics Unit.	All species production (9) 1984-2004
	FAO. © 2006-2010. National Aquaculture Sector Overview. United Arab Emirates. National Aquaculture Sector Overview Fact Sheets. Text by Al-Shaer, M. In: *FAO Fisheries and Aquaculture Department* [online]. Rome. Updated 27 July 2005. URL: www.fao.org/fishery/countrysector/naso_uae/en. Accessed April 27 2006.	Sector history, species cultured, locations
	UAE Centre for environmental and agriculture (UAEAGRICENT). 2006. URL: www.uae.gov.ae/uaeagricent. Accessed June 19, 2006. (link broken)	Species, locations
Vietnam	**1.** FAO. © 2006-2011. National Aquaculture Sector Overview. Viet Nam. National Aquaculture Sector Overview Fact Sheets. Text by Nguyen, T.P. & Truong, H.M. In: *FAO Fisheries and Aquaculture Department* [online]. Rome. Updated 10 October 2005. URL: www.fao.org/fishery/countrysector/naso_vietnam/en.Accessed 14 May 2007.	Sector info, species info, 2004 production of major species
	2. a) FISTENET. 2007. Some bivalve species with export value in Vietnam. URL: www.fistenet.gov/vn/.Accessed May 14, 2007. **b)** FISTENET. 2007. Marine Crab/Swimming Crab. URL: www.fistenet.gov/vn/.Accessed May 15, 2007. **c)** FISTENET. 2007. Aquaculture production by species group and by province. URL: www.fistenet.gov/vn/.	Info on major bivalve and gastropod species, Vietnamese names, distribution zone, culture status Info on crab culture, distribution of production, 2001-2004 portunus pelagicus production Aquaculture production of shrimp and fish by province 2001-03 – data provided by *T.N.Diep WWF Mekong*
	3. MOFI and Worldbank Group. 2005. Vietnam Fisheries and Aquaculture Sector Study. Final Report. "Fisheries sector trends and current status". 40p + appendices. Vietnam Ministry of Fisheries, Worldbank Group. URL: http://siteresources.worldbank.org/INTVIETNAM/Resources/vn_fisheries-report-final.pdf.Accessed May 14, 2007.	Regional production info, total aquaculture production 1991,96,2000-03, production (select years) info by region and species *Report notes GSOV and MOFI data aren't consistent with each other*
	4. MOFI.2006. Shrimp in brackish water 2002-2004, Aquaculture in tidal flats, Statistical data from Aquaculture Program. Vietnam Ministry of Fisheries.	Shrimp production by province (2004 by sp) 2002-04, bivalve production by province 02-04, prod by species 1999-05, by major region *stats compiled by Tham Ngoc Diep at Greater Mekong WWF- friend of J. Alder – data used in EASRD report*
	5. EASRD. 2006. Guidelines for Environmental Management of Aquaculture Investments in Vietnam. Rural Development and Natural Resources East Asia and Pacific Region. Prepared for Vietnam Ministry of Fisheries and Worldbank.116 p.	2005 production by broad category NBR, select specific sp and region data 1999-2005, fish and clam production by major producing region

Table A.1 Continued		
Primary References: Asia		
Country	**Source**	**Type of Information**
Vietnam (cont'd)	**6.** FAO.1991. Regional Seafarming Atlas: Vol II. Regional Seafarming Development and Demonstration Project RAS/90/002. National Inland Fisheries Institute, FAO. Bangkok. 71 p.	*C. rivularis, Pinctada* sp., *Pteria* sp., *Scylla serrata*, p. merguiensis, p. monodon production location, proportion of production of major taxon grouping
	7. GSOV. 2006. Production of farmed fish, shrimp by province. Statistical Data. General Statistics Office of Vietnam [online]. URL: www.gso.gov.vn/default_en.aspx?tabid=494&itemid=1635 Accessed January 22, 2007.	Production of fish, shrimp 1995-2003, by province
	8. Kleinen, J. 2003. Access to Natural Resources for Whom? Aquaculture in Nam Dinh, Vietnam. Maritime Studies (MAST). 2(2):39-63.	Production of shrimp, mud crab, fish, vang in Nam Dinh, Nghia Hung 1994-2002
	9. Vinh, D.T.T.2006. Aquaculture in Vietnam: development perspectives. Development in Practice. 16:5, 498-503	Total aquaculture production 1990-2002, some species, area info
	10. Phuong, N.T., Hai, T.N., Hien, T.T.T., Bui, T.V., Huong, D.T.T, Son, V.N. 2006. Current status of freshwater prawn culture in Vietnam and the development and transfer of seed production technology. Fisheries Science. 72:1-12	Brackish shrimp 2004 NBR, proportion of brackish, shrimp production to total aquaculture, species names
	11. Wilder, M., Phuong, N.T. 2002.The Status of Aquaculture in the Mekong Delta region of Vietnam: Sustainable Production and Combined Farming Systems. Paper published in the Proceedings of International Commemorative Symposium: 70th Anniversary of the Japanese Society of Fisheries Science. Fisheries Science. 68:1, p1-5.	Proportion of coastal aqua in Mekong in 2000, production of shrimp in Mekong 2000, species prod.
	12. Xan, L. 2007. Mariculture in Vietnam: Present Status and Strategy Development. Research Institute for Marine Aquaculture No. 1. 6 p. URL: www.encana.org/modules/tinyd6/index.php?id=6. Accessed March 15, 2001.	Main finfish species produced, production of marine fish, lobster in 2005, areas of cage culture
	13. FAO. 2008. FishStat Plus: Universal software for fishery statistical time series. "Aquaculture production 1950 – 2006". Version 2.31. FAO Fishery Information, Data and Statistics Unit.	Mollusc 1950-2003 Banana prawn 1964-2003 Tiger prawn 1963-2003 Indian prawn 1970-2003 Whiteleg prawn 2002/03
Yemen	FAO. © 2006-2010. National Aquaculture Sector Overview. Yemen. National Aquaculture Sector Overview Fact Sheets. Text by Salem, A. In: *FAO Fisheries and Aquaculture Department* [online]. Rome. Updated 1 February 2005. URL: www.fao.org/fishery/countrysector/naso_yemen/en. Accessed June 13, 2006.	Sector history, species cultured, locations, est of numbers-shrimp 04/05 *-national stats not reported to the FAO, no fisheries ministry website in 2006.*
No Commercial Mariculture production as of 2004 in: Iraq, Gaza, Georgia, Jordan, Macau SAR (CN), Maldives, Syria		

Table A.1 Continued

Primary References: Europe

Country	**Source**	**Type of Information**
Albania	Flloko, A. 2005. A short overview of the status of aquaculture in Albania. A short overview of the status of aquaculture in the Adriatic countries. *In*: Cataudella, S., Massa, F., Crosetti, D. (eds). 2005. Interactions between aquaculture and capture fisheries: a methodological perspective. Studies and Reviews. General Fisheries Commission for the Mediterranean. No. 78. Rome, FAO. 229p.	Regional info, mussel production by region 1990-2001, 1989-seabream and bass, mussel, shrimp 2000-2002 NBR.
	European Commission. 2009. EUROSTAT Data Explorer [online]. Fisheries – Aquaculture Production. V2.2.B.9. URL: http://epp.eurostat.ec.europa.eu/portal/page/portal/statistics/search_database. Accessed November 17, 2009.	Total annual production mussel 2007-2003, kuruma prawn 07, 99-97, sea bream 03-07
	UT. 2009. Europe Maps – "Albania Maps". Perry-Castañeda Library Map Collection [online]. University of Texas, Austin. URL: www.lib.utexas.edu/maps/. Accessed January 27, 2011	Map of Albania with administrative divisions
Bosnia-Herzegovina	FAO. © 2006-2009. National Aquaculture Sector Overview. Bosnia and Herzegovina. National Aquaculture Sector Overview Fact Sheets. Text by Hamzic, A**.** In: *FAO Fisheries and Aquaculture Department* [online]. Rome. Updated 1 February 2005. www.fao.org/fishery/countrysector/naso_bosnia/en. Accessed November 27, 2009.	Unpublished 2004 data by species, geographic and industry info
	European Commission. 2009. EUROSTAT Data Explorer [online]. Fisheries – Aquaculture Production. V2.2.B.9. URL: http://epp.eurostat.ec.europa.eu/portal/page/portal/statistics/search_database. Accessed November 17, 2009.	Total annual prod of all species, NBR 2002,03,05-07
Bulgaria	Ministry of Agriculture and Food. 2006. Annual Agriculture Reports. Executive Agency Fisheries and Aquacultures. URL: www.mzgar.government.bg/mz_eng/PosPaperFish_1311eng.htm. Accessed May 2, 2006.	Total production of black sea mussel 1999-2004
	Ministry of Agriculture and Forestry. 2007. National Strategic Plan for Fisheries and Aquaculture 2007-2013. National Agency for Fisheries and Aquaculture. Sofia, Bulgaria. 78 p.	Black sea mussel production 2005, general industry info
	Gippsland Aquaculture Industry Network Inc (GAIN). 2006. EU funding for mussel farming growth. GROWfish - sourced from the Sofia Echo. URL: www.growfish.com.au/content.asp?contentid=6491. Accessed May 2, 2006.	Location of mussel farm
	UT. 2009. Europe Maps – "Bulgaria Maps". Perry-Castañeda Library Map Collection [online]. University of Texas, Austin. URL: www.lib.utexas.edu/maps/. Accessed January 27, 2011	Map of Bulgaria with administrative divisions
	FAO. 2008. FishStat Plus: Universal software for fishery statistical time series. "Aquaculture production 1950 – 2006". Version 2.31. FAO Fishery Information, Data and Statistics Unit.	Black sea mussel (*m. galloprovincialis*) production estimates 1982-1998
Croatia	Croatian Chamber of Economy. 2007. Fishery and fish processing. Agriculture, Food industry, and Forestry Department. Zagreb, Croatia. Data modified from Croatian Bureau of Statistics (CBS).	Total prod of sea bass and bream, tuna, mussel and oyster 2001-2005
	Christofilogiannis, P. 2000. MARAQUA-Codes of Practice in Southern Europe Federation of European Aquaculture Producers (FEAP) Athens, GREECE URL: www.lifesciences.napier.ac.uk/maraqua/christo.htm. Accessed Nov 23, 2009.	Croatia mariculture prod 1992-1999
	FAO. © 2006-2009. National Aquaculture Sector Overview. Croatia. National Aquaculture Sector Overview Fact Sheets. Text by Piria, M. In: *FAO Fisheries and Aquaculture Department* [online]. Rome. Updated 1 February 2005. URL: www.fao.org/fishery/countrysector/naso_croatia/en. Accessed November 23, 2009.	Some industry history, geographic locations, scattered production #s
	Bruno, A. 1988. Situation of aquaculture in the MEDRAP (Mediterranean Regional Aquaculture Project) countries. Yugoslovia. Rome. 63 p. URL: www.fao.org/docrep/field/007/af025e/AF025E00.HTM Accessed: Nov 23, 2009	Oyster production, mussel prod, region 1988, estimate of prod in '85
	FAO. 1979. Development of coastal aquaculture in the Mediterranean region. The Socialist Federal Republic of Yugoslavia. Report of a mission to formulate a cooperative programme of activities, October 1978 - February 1979**.** 162 pg	Mussel and oyster prod estimate, by region 1980

Table A.1 Continued

Primary References: Europe

Country	Source	Type of Information
Croatia (cont'd)	Franicevic, V. 2005. A short overview of the status of aquaculture in Croatia. A short overview of the status of aquaculture in the Adriatic countries. *In*: Cataudella, S., Massa, F., Crosetti, D. (eds). 2005. Interactions between aquaculture and capture fisheries: a methodological perspective. Studies and Reviews. General Fisheries Commission for the Mediterranean. No. 78. Rome, FAO. 229p.	Some industry history, geographic locations, unpublished prod data from *Ministry of Agriculture and Fisheries* –tuna, bass and bream, mussel and oyster 1997-2002
	Institute of Oceanography and Fisheries (IZOR). 2004. Croatia – Annual Report 2004. Aquaculture national report. Split, Croatia. 7 p. Data adapted from Directorate of Fisheries annual reports. URL: www.izor.hr/smeeting/documents.htm. Accessed May 2006.	Seabass and seabream, mussel, oyster, tuna 1999-2004
	Sarusic, G. 2000. Mariculture on Croatian islands. Ribarstvo. 58(3):111-118	Euro bass and bream prod 1996
Cyprus	UT. 2009. Europe Maps – "Cyprus Maps". Perry-Castañeda Library Map Collection [online]. University of Texas, Austin. URL: www.lib.utexas.edu/maps/. Accessed January 27, 2011	Map of Albania with administrative divisions
	DFMR. 2006. Cyprus Marine Aquaculture Production 1988-2005. Data provided by Kyriacou, Y. Department of Fish and Marine Research.	Production all species combined 1988-2005, tuna, bream, bass 04/05, production proportions for these species also provided in personal communication.
	FAO. © 2006-2011. National Aquaculture Sector Overview. Cyprus. National Aquaculture Sector Overview Fact Sheets. Text by Papadopoulos, V. In: *FAO Fisheries and Aquaculture Department* [online]. Rome. Updated 9 November 2010. URL:www.fao.org/fishery/countrysector/naso_cyprus/en. Accessed October 31, 2006.	General sector info, production of some species in 2004 (DFMR data)
	FAO. 2008. FishStat Plus: Universal software for fishery statistical time series. "Aquaculture production 1950 – 2006". Version 2.31. FAO Fishery Information, Data and Statistics Unit.	G.Seabream 1988-04 S.Seabream 1995-2004 Seabass 1988-04 Tuna 04/ White prawn 1995-04 Red porgy 1995-97, 2002-04 *Unclear what was used fishstat vs dfmr*
France	AGRESTE. 2006. Publications GraphAgri 2006. [online] URL: www.agreste.agriculture.gouv.fr/publications/graphagri/. Accessed July 16, 2007. AGRESTE. 2006. Pays de la Loire. La mytiliculture dans les Pays de la Loire. Ministère de l'alimentation, de l'agriculture et de la pêche. Mai 2006. Paris. 4p. AGRESTE. 2005. Recensement de la conchyliculture 2001. Agreste Cahiers. Ministère de l'alimentation, de l'agriculture et de la pêche. No 1- Février 2005. Paris. 16-17 pp. AGRESTE. 2003. Premier recensement de la conchyliculture. Agreste primeur. Ministère de l'alimentation, de l'agriculture et de la pêche. No 126 – Mai 2003. Paris. 4p. AGRESTE. 2000. La pisciculture marine Française, une activité récente et pionnière en Europe. Agreste Cahiers. Revue trimestriel. No 2 –Juin 2000. Ministère de l'alimentation, de l'agriculture et de la pêche. Paris. 39-48 pp. AGRESTE. 1999. La statistique agricole. Agreste primeur. No 54 – Mars 1999, No 59– Juin 1999. Ministère de l'alimentation, de l'agriculture et de la pêche. Paris. 4 p.	Turbot, seabass and bream production 1995, 97, 99, 2000, 04, Mussel, oyster, other bivalves 1991-2004 NBR (bar graph), 2002 by region Mussel, oyster in PdeL 2002, by method Mussel, oyster production 2001, by region Huîtres creuses by region 2001, NBR production of other bivalves Estimate Atl. salmon production by region 1998 Turbot, seabass and bream production by region 1997
	OFIMER. 2006-2007. Les chiffres clés de la filière pêche et aquaculture en France. Edition 2006/2007. 32 p.	NBR production, broad categories 2004/05 – *data from DPMA*

Table A.1 Continued

Primary References: Europe

Country	Source	Type of Information
France (cont'd)	FAO. © 2005-2009. National Aquaculture Sector Overview. France. National Aquaculture Sector Overview Fact Sheets. Text by Lacroix, D. In: *FAO Fisheries and Aquaculture Department* [online]. Rome. Updated 25 July 2005. URL:www.fao.org/fishery/countrysector/naso_france/en. Accessed December 9, 2009.	General sector info, production of some species in 2004
	IFREMER 2007. Aquaculture-Pédagogie [online]. URL: http://aquaculture.ifremer.fr/pedagogie. Accessed July 16, 2007. Gerard, A. 2006. Pisciculture marine – Eléments de prospective. Direction des Programmes et de la Stratégie. Mars 2006. IFREMER. 131-146 pp. URL: www.ifremer.fr/docelec/doc/2006/rapport-1506.pdf. Accessed July 16, 2007.	Regions where species are produced, production by bivalve species and region (proportions) 2001 King scallop production 1982-03 in Brest (bar graph) Bar, dorade 1985-2002 S.ocellatus in Antilles 96,01,03,05 crustaceans 2002 Overview of overseas territories, some production #s 1999, 2004, 05
	De la Pomélie, C., Paquotte, P. 2000. The experience of offshore fish farming in France. CIHEAM Options Méditerranéenes. Série B, Études et Recherches. No 30. 25-32 pp.	Total production of major fish species 1990-1996 – *source is a mix of Ifremer, MinAg, FFA data*
	Chaussade, J., Corlay, J-P. 1988. Atlas des pêches et des cultures marines en France. Ministère de la Mer. Montpelier, Reclus. 103 p.	Detailed areas of culture, some %ages, some species info
	FAO. 1979. Development of coastal aquaculture in the Mediterranean region. Annex 1- Summary reports of the Mission's visit to countries in the Mediterranean region. Report of a mission to formulate a cooperative programme of activities October 1978- February 1979. 9-14 pp. URL: www.fao.org/docrep/006/N7865E/N7865E00.htm. Accessed July 16, 2007.	Oyster, mussel production 1977, general regions
	European Commission. 2010. Eurostat Database: Aquaculture production. URL: http://epp.eurostat.ec.europa.eu/portal/page/portal/fisheries/data/database. Accessed Jan 23, 2007.	Scattered production and species 2007-1950 (not 2001) divided by sea. ~75% of years of dataset.- *eurostat missing some species, has additional of others*
Germany	Rosenthal, H., Hilge, V. 2000. Aquaculture production and environmental regulations in Germany. J.Appl. Ichthyol. Blackwell Wissenschafts-Verlag, Berlin. 16: 163-166	Industry history, species info and locations, production mussel 1987-1999
	FAO. © 2007-2009. National Aquaculture Sector Overview. Germany. National Aquaculture Sector Overview Fact Sheets. Text by Braemik, U. In: *FAO Fisheries and Aquaculture Department* [online]. Rome. Updated 10 October 2005. URL: www.fao.org/fishery/countrysector/naso_germany/en. Accessed October 27, 2009.	Species, 2006 production of finfish and mussel, some geog locations
	European Data Service. Federal Statistical Office of Germany. 2009. EUROSTAT Data Explorer [online]. Fisheries – Aquaculture Production. V2.2.B.9. European Commission.URL: http://epp.eurostat.ec.europa.eu/portal/page/portal/statistics/search_database. Accessed November 17, 2009.	Total annual production by sp and environment. 1950-2007
Greece	NSSG. 2008. Aquaculture –Fishculture Tables. National Statistical Service of Greece [online]. URL: www.statistics.gr/portal/page/portal/ESYE/PAGE-themes?p_param=A0201. Accessed Oct 27th, 2009.	Production by sp and culture type 2004/2005
	NSSG. 2001-2005. Aquaculture-Fishculture Yearbooks. Primary Sector Statistics. National Statistical Service of Greece. Vol. 99, 101, 103, 108, 111, 114, 122. Pireas/Athens.	Production by species and Periphery 1996-2002, in harcopy *Translation assistance from V. Karpouzi*
	NSSG. 2005. FAO AQ-NS1 - Form for reporting statistics on aquaculture of fish, crustaceans, molluscs, etc. by species, environment and fishing areas. National Statistical Service of Greece. Athens	Production by species and env't 1997-2004, not by region, *data provided by N. Tsiligaki, head of data provision NSSG*

Table A.1 Continued		
Primary References: Europe		
Country	**Source**	**Type of Information**
Greece (cont'd)	FAO. © 2006-2009. National Aquaculture Sector Overview. Greece. National Aquaculture Sector Overview Fact Sheets. Text by Christofilogiannis, P. In: *FAO Fisheries and Aquaculture Department* [online]. Rome. Updated 10 October 2005. URL: www.fao.org/fishery/countrysector/naso_greece/en. Accessed October 27, 2009.	Additional species produced, explanation of discrepancies
	Argyrou, L.H., Stergiou, K.L. 1990. Aquaculture production in Greece, 1980-1988. Rapp. Comm. int. Mer Médit. 32(1)	Avg. production mussel, bass/bream 1986-88
	Stephanis, J. 1996. Mediterranean aquaculture industry trends in production, markets and marketing. In: Chatain, B., Saroglia, M., Sweetman, J., Lavens, P., eds. Seabass and Seabream Culture: Problems and Perspectives. Oostende: EAS; 1996. p. 7-23. 388 p.	Seabass/bream production 1988-1994
Italy	Marino, G., Ingle, E., Cataudella, S. 2005. A short overview of the status of aquaculture in Italy. A short overview of the status of aquaculture in the Adriatic countries. *In*: Cataudella, S., Massa, F., Crosetti, D. (eds). 2005. Interactions between aquaculture and capture fisheries: a methodological perspective. Studies and Reviews. General Fisheries Commission for the Mediterranean. No. 78. Rome, FAO. 229p.	General info on sp produced, some general geog info by sp, industry info Production of major finfish species NBR 1987-2001, bivalves 1991-2001 *–data from ICRAM-API*
	Marino, G., Ingle, E., Cataudella, S. 1999. Status of aquaculture in Italy (1998). *In*: "Aquaculture planning in Mediterranean countries", IAMZ-CIHEAM. Cahiers Options Mediterrranées, 43:117-126	Contains ICRAM data in bar graphs of major sp 1992-1997, NBR
	Ministero delle Politiche Agricole e Forestali. 1999. Table – "Produzione dell'acquacoltura italiana in tonnellate e corrispettivo valore in milioni di lire per il 1998". PON Pesca. 36 p.	Contains ICRAM/API data production by major species NBR in 1998, total production by region
	Iandoli, C. 1999. Marine fish farming in Italy. CIHEAM. Cahiers Options Mediterrranées, p.33-41	Contains ICRAM prod of major species, general info on regions 1988-1997
	National Institute of Agricultural Economics (INEA). 2007. Programma Operativo Regionale Sicilia 2000-2006. Analisi del settore della pesca e dell'acquacoltura. Allegato 2. N. 1260/99. 12 p.	Sicily production of marine fish 1998 *- from ICRAM-API data*
	ISMEA. 1999. La pesca e l'acquacoltura in Veneto. Istituto di Servizi per il Mercato Agricolo Alimentare. 74 p.	Production of main fish, shellfish sp in Veneto 1993, 1998
	Report to the European Commission DG Fisheries. 2004. Study of the market for aquaculture produced seabass and seabream species. Final Report 2002-2004. University of Stirling.	Production of seabass and bream 1998-2002 NBR
	Malorgio, G., Pasolini, B., Leonelli, P.S. 2005. Primo rapport sull'economia del mare in Emilia-Romagna 2006. Osservatorio Economia Ittica. Regione Emilia-Romagna. Greentime SpA, Bologna. 43-53 pp.	1999-2004 mussel production in Emilia-Romagna (broken down by province), 2004 clam
	Veneto Agricoltura. 2006. La pesca e l'acquacoltura in Friuli Venezia Giulia. Osservatorio Socio Economico della Pesca dell'Alto Adriatico. Adrifish. Chioggia. 12 p. Veneto Agricoltura. 2006. La pesca e l'acquacoltura in Emila Romagna. Osservatorio Socio Economico della Pesca dell'Alto Adriatico. Adrifish. Chioggia. 13 p. Veneto Agricoltura. 2006. La pesca e l'acquacoltura nel Veneto. Osservatorio Socio Economico della Pesca dell'Alto Adriatico. Adrifish. Chioggia. 22 p.	production of mussel, clam 2003 in Fri-Ven-Giu, Emil-Rom Friu-Ven-Giul prod of eel 2003, marine fish 2001 Veneto eel, finfish, mussel, clam 2003 *- data from ICRAM-API*
	Megapesca. 1998. Italy - Marine aquaculture production. Megapesca Lda. Portugal. URL: www.megapesca.com/fishdep/IT3/IT3D23.htm. Accessed May 10th, 2007.	Contains IREPA estimate of ICRAM data by sp group 1997 by region (NUTS II)
	Federation of European Aquaculture Producers (FEAP). 2010. National Aquaculture Production -Italian production. URL: www.feap.info/production/countries/italy/itprod_en.asp Accessed January 5, 2010.	Prod NBR seabass and bream, eel 1996-2007, meagre 03-07

Table A.1 Continued		
Primary References: Europe		
Country	**Source**	**Type of Information**
Italy (cont'd)	Ingle E. et al. 2002. Realizzazione di una banca dati sull'acquacoltura in Italia: prosecuzione del rilevamento sistematico dello stato di diffusion della technolgia e del dati di produzione nel settore dell'acquacoltura e della maricoltura. Report 4C32, prepared for the Ministero delle Politiche Agricole e Forestali.	Data in this paper modified by ICRAM-API to produce tables of Prod 1987- 2001 of major sp NBR in this FAO doc
	Prioli, G. 2001. Censimento nationale sulla molluschicoltura del Consorzio Unimar. Unimar Osservatorio technico-biologico, Roma, Italy. 97 p.	Mussel and manila clam prod 2001-1991
	FAO. 2008. FishStat Plus: Universal software for fishery statistical time series. "Aquaculture production 1950 – 2006". Version 2.31. FAO Fishery Information, Data and Statistics Unit.	seabass/bream <1983-73/70, mussel 07-02<1989-1956 Meagre 04,02 Manila clam 07-02, 1989-85 Mullet 07-04, <1985-1950 Tuna 07-02 / Prawn 07-89 Oyster 07-81 / Porgies 07-00
Malta	Ministry for Rural Affairs and the Environment (MRAE). 2006. Malta Centre for Fisheries Sciences – Aquaculture. URL: www.maltafisheries.gov.mt/. Accessed Dec 15th, 2006.	Species, general geog locations, beginning of industry, tuna 2000,01,03, bream and bass 05
	Ministry for Resources and Rural Affairs (MRRA). 2009. Fish and Farm Regulation and Control – Aquaculture. URL: http://vafd.gov.mt/aquaculture. Accessed Nov 4th, 2009.	Species, industry history, geog locations – by farm, prod of bass and bream, 1990,99, 2000-02, 07, tuna 2006
	Agius, C. 1999. Strategies for aquaculture development in small Mediterranean island State: Malta. In: Aquaculture planning in Mediterranean Countries/ Planification de l'aquaculture dans les pays méditerranéens. Proceedings of the Workshop of the CIHEAM Network. Selam, Tangiers. 12-14 March 1998. CIHEAM/FAO/INRH, Zaragoza. *Options Méditerranéennes*. *Séries Cahiers* 43: 41-44.	Production of bass and bream 1991-1998
Montenegro	Macic, V. 2005. A Short Overview of the Status of Aquaculture in Montenegro. *In*: Cataudella S., Massa, F.; Crosetti D. (eds) 1) AdriaMed Expert Consultation "Interactions between Aquaculture and Capture Fisheries". AdriaMed Technical Documents. No.18. GCP/RER/010/ITA/TD-18, Termoli, 2005. (in prep). 2) Interactions between aquaculture and capture fisheries: a methodological perspective. *Studies and Reviews General Fisheries Commission for the Mediterranean*. No.78. Rome, FAO. 2005: 12-35 pp.	Some industry history, geographic regions, species cultured, prod estimate for seabass and bream combined
	FAO. 2008. FishStat Plus: Universal software for fishery statistical time series. "Aquaculture production 1950 – 2006". Version 2.31. FAO Fishery Information, Data and Statistics Unit.	Eel and mussel prod 1992-2005
Portugal	Bernardino, F.N.V. 2000. Review of aquaculture development in Portugal. J. Appl. Icthyol. 16:196-199	Sp names, industry history, total prod of some sp 1993-1997 –bar graph
	Direcção-Geral das Pescas e Aquicultura (DGPA). 1998-2009. Publicações Recursos da Pesca. Série Estatisca. Ministério de Agricultura, do Desenvolvimento Rural e das Pescas. Lisboa. Vol 11-22.	Total national production by species (in portugese) in yearbooks 1997,99-2007
	Instituto Nacional de Estatistica (INE). 2007. Database – Production of aquaculture establishments (t) by geographic location (NUTS-2002), type of water (aquaculture) and production system. URL: www.ine.pt. Accessed Nov 6th, 2009.	Production by species, by region 2004
	Instituto Nacional de Estatistica Portugal (INE). 2006. Estatisticas da Pesca – 1999-2004. URL: www.ine.pt. Accessed Nov 6th, 2009.	Yearbook production by species, by region 1999-2004
	Pita, C., Marques, A., Erzini, K., Noronha, I., Houlihan, D., Dinis, M.T. 2001. Socio-economics of the Algarve fisheries sector: a review. PowerPoint Poster. CCMAR, Universidade de Algarve. URL: www.abdn.ac.uk/aqcess/poster_algarve.ppt. Accessed Jan 28, 2009.	Marine prod by region, 1999
	Silvert, W. 2003. Country report – Portugal. Portuguese Institute for Fisheries and Sea Research. Submitted to 2003 ICES Working Group on Environmental Interactions of Mariculture (WGEIM). Vigo, Spain. URL: http://ciencia.silvert.org/eim/pt2003/pt2003.htm. Accessed Jan 29, 2008.	Bar graph production of major sp 1990-2001, some geog info.

Table A.1 Continued		
Primary References: Europe		
Country	**Source**	**Type of Information**
Slovenia	Statistical Office of the Republic of Slovenia. 2006. SI-STAT Data Portal – Environment and natural resources – fishery. URL: www.stat.si/pxweb/Database/Environment/15_agriculture_fishing/08_15191_fishery/08_15191_fishery.asp. Accessed Nov 25th, 2009.	Total production European seabass, gilthead seabream, other marine fishes, medit mussel, other moll. 1990-2005 (kg) NBR
	Kadoič, M. 2005. A short overview of the status of aquaculture in the Adriatic countries. A short overview of the status of aquaculture in Slovenia. Cataudella, S.; Massa, F.; Crosetti, D. (eds.) Interactions between aquaculture and capture fisheries: a methodological perspective. *Studies and Reviews. General Fisheries Commission for the Mediterranean.* No. 78. Rome, FAO. 2005. 229p.	Industry history, species cultured, geography of culture
Spain	Departament d'Agricultura, Ramaderia I Pesca (DARP). 2005. Estadístiques d'aqüicultura – Producció per espècies Durant el període 1992 – 2004. Generalitat de Catalunya.URL: www.gencat.net/darp/c/pescamar/aquicola/aqui0206.htm. Accessed May 17th, 2005. Departament d'Agricultura, Ramaderia I Pesca (DARP). 2008. Estadística de producció d'aqüicultura 2007. Generalitat de Catalunya. URL: www.gencat.net/darp/. Accesed Nov 29th, 2009.	**Catalan** production by sp 1992-2004, 2005-07
	Asociación Empresarial de Productores de Cultivos Marinos (APROMAR). 2004. La acuicultura marinade pesces en España 2004. Cadiz, España. 39 p. Asociación Empresarial de Productores de Cultivos Marinos (APROMAR). 2009. La acuicultura marinade pesces en España 2009. Cadiz, España. 39 p.	Production by species, by all region, 2000-2005, 2006-08
	Consejaría de Agricultura y Pesca Junta de Andalucía. 2009. Estadiscas Pesqueras - Producción Acuicola. URL: www.juntadeandalucia.es/agriculturaypesca/portal/www/portal/com/bin/portal/DGPesca/Estadisticas_Pesqueras/estadisticas_1985_1999/datos_acuicultura.pdf. Accessed May 17th, 2005.	**Andaluz** production by major species 1999-1985, 2008
	Ministry of the Environment and Rural and Marine Affairs (MARM). 2009. Aqüicultura 2005-2008. Producción. Subdirección General de Estadística del MARM (MAPA). URL: www.mapa.es/en/pesca/pags/jacumar/presentacion/acuicultura_es.htm#art3 and www.mapa.es/estadistica/pags/pesquera/acuicultura/produccion/2005-2008_01_Prod_anno_tipo_agua_grupo.pdf. Accessed Nov 29th, 2009	Brief history, some geographical info, production of some species 2007, 05-08
	Sánchez-Mata, A. Mora, J. 2000. A review of aquaculture in Spain: production, regulations and environmental monitoring. J. Appl. Ichtyol. 16: 209-213	Total national prod by some sp. 1998, **Galicia** prod by sp 1997
	Basurco, B., Larrazabal, G.1999. Situación actual de la pisicultura marina en España. Productos del Mar. 137-138: 97-104.	Industry info, total prod 1990-2000 data actually from APROMAR, but not accessible online
	Xunta de Galicia. 2004. Galicia 2004 – La pesca – La acuicultura: el future del sector. URL: www.xunta.es/portada. Accessed Nov 29th, 2009.	Production by most species in **Galicia** 2002
	Instituto Gallego de Estatística (IGE).2009. Producción de acuicultura mariña en Galicia. URL: www.ige.eu/igebdt/selector.jsp?COD=2705&paxina=002001&c=0302002002. Accessed Nov 29th, 2009.	Production by species in **Galicia** 2007/08
	Viceconsejaría de Pesca del Gobierno de Canarias. 2009. Evolución de la producción de la acuicultura en Canarias. Plan Regional de Ordenación de la Acuicultura de Canarias. Servicio de desarrollo pesquero. URL: www2.gobiernodecanarias.org/agricultura/pesca/cultivosmarinos/estadisticas.pdf. Accessed Dec 9th, 2009.	**Canaries** -Production by sp and island 1998-2005
	Comunidad Autónoma de la Region de Murcia (CARM). 2008. Acuicultura en la Región de Murcia. DG Ganadería y Pesca- Servicio de Pesca y Acuicultura. URL:www.carm.es/neweb2/servlet/integra.servlets.ControlPublico?IDCONTENIDO=1710&IDTIPO=100&RASTRO=c432$m1262,1267. Accessed Nov 29th, 2009.	**Murcia** - Production by major sp 1993-2006 *numbers v. different then APROMAR

Table A.1 Continued

Primary References: Europe

Country	Source	Type of Information
Spain (Cont'd)	Instituto Valenciano de la Exportación (IVEX). 2009. Acuicultura y pesca de la Comunitat Valenciana. Generalitat Valenciana. URL: www.ivex.es/ . Accessed Nov 29th, 2009.	Prod of fish sp in **Valencia** 06-08
	European Commission. 2009. EUROSTAT Data Explorer [online]. Fisheries – Aquaculture Production. V2.2.B.9. URL: http://epp.eurostat.ec.europa.eu/portal/page/portal/statistics/search_database. Accessed November 17, 2009.	Varies – all production for a few species, some infill, divided by Med and Atlantic - ~40% of dataset , *Eurostat and other sources often not the same in tonnage and species*
Turkey	SIS. 1994-2004. Aquaculture Production. The State Institute of Statistics. Fishery Statistics.	Production of salmon, sea bream, two-banded bream, trout, sea bass, mussel 1994-2004 *-emailed by SIS following data request*
	Deniz, H., Korkut, A.Y., Tekelioglu, N. 2000. Developments in the Turkish Marine Aquaculture Sector Options Méditerranéennes. Série B : Etudes et Recherches:30. Advanced Course of the CIHEAM Network on Technology of Aquaculture in the Mediterranean on "Mediterranean Offshore Mariculture", Zaragoza (Spain), 20-24 Oct 1997.	Species, information, production 1996-98 Shrimp 96-98
	Deniz, H. 2000. Marine aquaculture in Turkey and potential for finfish species. Cahiers Options Méditerranéennes **47**:349–358.	Sector information, areas ands species of culture
	New, M. Insull, D., Ruckes, E., Sagnolo, M. 1987. The markets for the prime Mediterranean species – Sea bass, Sea bream, Mullets, and Eel – and their links with investment. Annex 1 – Notes on the Status of the culture and fisheries of prome species in the Mediterranean region. A summary of the information generated by an ADCP/MEDRAP Workshop on this topic held at Ente di Sviluppo Agricolo del Veneto (ESAV), Villanova di Motta di Livenza, 9-11 December 1986. URL: www.fao.org/docrep/S3463E/s3463e0a.htm Accessed December 15, 2005.	1982, 85-87 production data of sea bream, sea bass, mullet, eels
Ukraine	FAO. 2004. Fishery country profile – Ukraine. URL: www.fao.org/fi/oldsite/FCP/en/UKR/profile.htm. Accessed Nov 19, 2009.	General industry history, info, location of mussel and mullet farming
	FAO. 2008. FishStat Plus: Universal software for fishery statistical time series. "Aquaculture production 1950 – 2006". Version 2.31. FAO Fishery Information, Data and Statistics Unit.	species production (6) 1986-2006 – *no info in eurostat, some of this data could be capture?*

No Commercial Mariculture production as of 2004 in: Belgium, Estonia, Georgia, Latvia, Lithuania, Poland, Romania

Table A.1 Continued		
Primary References: North Europe		
Country	**Source**	**Type of information**
Denmark	FAO. 2009. National Aquaculture Sector Overview. Denmark. National Aquaculture Sector Overview Fact Sheets. Text by Larsen, K. In: *FAO Fisheries and Aquaculture Department* [online]. Rome. Updated 1 February 2005. URL: www.fao.org/fishery/countrysector/naso_denmark/en. Accessed 27 October 2009.	Industry history, species and environments of production
	Ministry of Food, Agriculture and Fisheries. 1999-2008. Yearbook of Fishery Statistics. Danish Directorate of Fisheries. URL: www.fvm.dk/Static_Statistic_Tables.aspx?ID=24951. Accessed October 2009.	Production by county by species 1999-2008 Less detail farther back 1990-1978 interpolated- based on assumption that production declines by 10% each year before 1990, by 20% in 79/78
	UT. 2009. Europe Maps – "Denmark Maps". Perry-Castañeda Library Map Collection [online]. University of Texas, Austin. URL: www.lib.utexas.edu/maps/. Accessed January 27, 2011	Map of Denmark with administrative regions (old)
Falkland Is. (UK)	FAO. 2008. FishStat Plus: Universal software for fishery statistical time series. "Aquaculture production 1950 – 2006". Version 2.31. FAO Fishery Information, Data and Statistics Unit.	Production of mussel and oyster NBR 1t 2004-06
Faroe Is. (DK)	Statistics Faroe Islands. 2009. Business Statistics – Fishing, aqua and agriculture. URL: www.hagstova.fo/portal/page/portal/HAGSTOVAN/Statistics_%20Faroe_Islands. Accessed October 20, 2009.	Production of salmon and trout, gutted weight 1996-2008
	FAO. 2009. Fishery and Aquaculture Country profiles. Faroe Islands - Profiles home. Fishery and Aquaculture Country Profiles. In: *FAO Fisheries and Aquaculture Department* [online]. Rome. Updated 5 August 2004. URL: www.fao.org/fishery/countrysector/FI-CP_FO/en. Accessed October 19th, 2009.	Industry history, species and environments of production
	Norwegian Seafood Federation. 2006. Status and potential for the aquaculture industry in Nordic countries. Presentation by Hjelt, K.	2002 production of Atl. salmon and trout, farm locations
	ANON. 1989. Salmon culture in the Faroe Islands – Faroe Islands – Foreign fishery developments. Marine Fisheries Review. 3 p.	Atl. salmon production 1982, 85, 97 – *potential confusion with gutted vs whole wts.*
Finland	Finnish Game and Fisheries Research Institute. 2008. Official Statistics of Finland. Aquaculture 2007, 2005, 2004. URL www.rktl.fl/ Accessed October 14th, 2009.	In Finnish (some English). Total annual production of food fish-2004-1994, bar graph 1980-2007, mostly categorized as 'sea'-not sp, 2007 by area List of species (2004), Map with admin regions
	UT. 2009. Europe Maps – "Finland Maps". Perry-Castañeda Library Map Collection [online]. University of Texas, Austin. URL: www.lib.utexas.edu/maps/. Accessed October 14th, 2009	Map with admin regions
	Saarni, K., Setala, J.,Honkanen, A., Virtanen, J. 2003. An overview of salmon trout aquaculture in Finland. Aquaculture economics and management. Taylor and Francis. 7(5):335-343.	Rainbow trout industry info, graph of production back to 1978 Main production areas in 1999 –*data actually from FGFRI*
Iceland	Kristinsson, J.B. 1992. Aquaculture in Iceland – history and present status. Búvísindi. Icel. Agr. Sci. Reykjavik. 6: 5-8.	Industry history, NBR production of salmon, trout 1980-1990
	Icelandic Ministry of Fisheries and Agriculture. 2009. Aquaculture. URL: www.fisheries.is/aquaculture/species/. Accessed Oct 22, 2009.	Industry history, species produced, some regional info, production #s 1985-2008 (bar graphs) –*data from Directorate of Fisheries (in Icelandic), stats ministry only gives export data?*

Table A.1 Continued		
Primary References: North Europe		
Country	**Source**	**Type of information**
Ireland	BIM. 2004. Irish aquaculture production 2003. Prepared by Robinson, G. Bord Iascaigh Mhara. 21 p.	Production by species NBR 2003/03, production % by county and some #s, bar graph data 1996-2003 *Also contains Atl. salmon conversion rates for gutted wt etc.*
	BIM. 2003. Fish Farming Information – Maps. Bord Iascaigh Mhara. URL: www.bim.ie/templates/maps.asp?node_id=271. Accessed February 1, 2010	Location maps of farming licenses by county and species
	Marine Institute. 1996. National activities in the field of aquaculture: Ireland. Griffith, D. De G. (Ed). Fishery Leaflet 171. Dublin. 20 p.	Industry history, Production by species NBR 1994 Production by major species NBR 1980-1994 – *data actually from BIM*
	Breathnach, P. 1992. The development of the Irish fish farming industry. Irish Geography 25: 2, 182-187	Industry overview, general site locations of major sp. in 1990
	Central Statistics Office Ireland (CSO). 2003. Database Direct- Aquaculture production by species, year and statistic. URL: www.cso.ie/px/pxeirestat/Dialog/varval.asp?ma=AFGA1&ti=Aquaculture+Production+by+Species,+Year+and+Statistic&path=../Database/EireStat/Fisheries/&lang=1. Accessed Feb 01, 2010.	National production of broad species categories and salmon 1994-2002
	MERC Consultants. 2008/2007/2005. Status of Irish Aquaculture 2007/2006/2004. Eds. Browne, R., Deegan, B. O'Carroll, T., Norman, M., Ó'Cinnéide, M. Report prepared for Marine Institute, Bord Iascaigh Mhara and Taighde Mara Teo. 5-22, 96 pp.	Location of licenses, new species of culture, production by species 1990-07 NBR – *most data actually from BIM*
	European Commission. 2010. Eurostat Database: Aquaculture production. URL:http://epp.eurostat.ec.europa.eu/portal/page/portal/fisheries/data/database . Accessed Oct 29, 2010.	Turbot 2000-98, 96/95 Atl. salmon ('74)/ *o. mykiss* ('77)/ mussel ('65) oyster ('70) <1979
Netherlands	Central Bureau voor de Statistiek (CBS). 2010. Zee en kustvisserij: vloot, visvangst en productie aquacultuur. Statline. URL: http://statline.cbs.nl/StatWeb/publication/?VW=T&DM=SLNL&PA=7203vloo&D1=a&D2=a&HD=100204-2056&HDR=T&STB=G1. Accessed February 4th, 2010.	Mussel production by sea 2007-1993 converted from mill. Kg – *data discrepancies with FAO for oyster, lack of clarity for some species whether capture or not*
	Wageningen UR. 2010. Aquacultuur – schelpdierteelt- statistische informatie. URL: www.aquacultuur.wur.nl/NL/Schelpdierteelt/Statistische+informatie/. Accessed February 4th, 2010.	Euro. oyster production NBR 1992-2003 – *site indicates data is a mix of FAO/ FEAP/ NEVEVI*
	Smaal. A.C., Lucas, L. 2000. Regulation and monitoring of marine aquaculture in the Netherlands. J. Appl. Ichthyol. 16:187-191	General industry info, geog info, species names
	European Commission. 2010. Eurostat Database: Aquaculture production. URL:http://epp.eurostat.ec.europa.eu/portal/page/portal/fisheries/data/database Accessed Oct 29, 2010.	Blue mussel 1992-50/ Euro. oyster 04/05 / Cupped oyster '05-87 / Turbot '07-99
Norway	Norwegian Seafood Federation. 2006. Status and potential for the aquaculture industry in Nordic countries. Presented by Hjelt, K.	Estimated total production of species NBR 1995-2004
	Statistics Norway. 2009. Sales of shellfish, by fish species. 2000-2007. URL: www.ssb.no/english/subjects/10/05/nos_fiskeoppdrett_en/nos_d422_en/tab/tab6.html. Accessed October 2009 Statistics Norway. 2007. Sales of slaughtered fish for food. Quantity, by fish species and county. 1998, 2000, 2001, 2002, 2003, 2007. URL: www.ssb.no/english/subjects/10/05/nos_fiskeoppdrett_en/nos_d422_en/tab/tab1.html (Accessed October 28th, 2010) and URL: www.ssb.no/english/subjects/10/05/nos_fiskeoppdrett_en/nos_d317_en/tab/tab-3.2.... Accessed August 8th, 2005.	County breakdown, some interpolation for minor producing regions and for some of 2003, 05 Production of fish NBR 1997 – 2007, by county 2007 – *data after 2004 not incorporated*, Production of fish NBR 1971 – 2003 Shellfish production NBR 2000-2007

Table A.1 Continued

Primary References: North Europe

Country	Source	Type of information
Norway (cont'd)	Fiskeridirektoratet. 2000. Statistikk fra akvakultur. Sale of farmed fish, other species than salmon and trout – sale of shellfish. URL: www.fiskeridir.no/statistikk/akvakultur. Accessed October 2009.	Shellfish and minor fish sp. production 1994 – 2000, by major region
	Stiftelsen Norsk Skjellforum. 2004. Publikasjoner: Statistikk. "Salg av skjell I 2002". URL: www.skjell.com/. Accessed October 2009.	Production of scallop, oyster, mussel 1999-2002, by major region 2002
Sweden	Statistika centralbyrån (SCB) and Fiskeriverket. 1985-2004. Sveriges Officiella Statistik – Statistiska Meddelanden- Vattenbruk. URL (2001-2004): www.scb.se/. Accessed October 14th, 2009	In Swedish. Total annual mariculture production of rainbow trout (some marine culture, salmon, mussel, oyster, eel, arctic char, Rainbow trout 1985-2004, by county
	Sverigesurfen. 2009. Kommuner I Sverige. URL: www.sverigesurfen.com/sverigekarta.htm. Accessed October 14th, 2009.	Map of counties and associated codes – in Swedish
	Federation of European Aquaculture Producers (FEAP). Aquamedia. Production: Sweden. URL: www.feap.info/production/countries/sweden/sweprod_en.asp?. Accessed Oct, 2009.	Total annual production for eel, Arctic char 1997-2005
United Kingdom	**SCOTLAND:** Fisheries Research Service. 1997-2009. Scottish Fish Farms Annual Production Survey 1996-2008. Report prepared for the Scottish Executive by FRS Marine Laboratory Aberdeen. 47p.	Shellfish species produced, regional production 1991-2000 (oyster and scallop in individuals but incl. conversion weights) National production 1988-08 Salmon production by region, 1994 - 2007, 1986 to 2001 NBR Production of minor fish species 1999-2008 sw *o. mykiss* 1999-2008 trout 1991-2004 (incl fw)
	Scottish Executive. 2003. Advice note: Marine fish farming and the environment. Scottish Executive Environment and Rural Affairs Department. 120 p. URL: www.scotland.gov.uk/library2/doc06/mff-25.htm. Accessed Jan 2010.	Scattered info in industry, production #s
	NORTHERN IRELAND: Department of Agriculture and Rural Development (DARDNI). 2000. Report on the sea and inland fisheries of Northern Ireland 1999. Commercial aquaculture. Table 16: Production by commercial shellfish farms in Northern Ireland. URL: www.dardni.gov.uk/fisheries/fish0012.htm.Accessed October 2009. Department of Agriculture and Rural Development (DARDNI). 2006. Table: Production by commercial shellfish farms in Northern Ireland and Salmon and trout production by commercial fish farms in Northern Ireland. URL: www.dardni.gov.uk/fisheries/. Accessed October 2009.	Broad category shellfish production NBR 1994-1999 Shellfish prod 98-03 Salmon and trout (combined 98-03), NBR
	ENGLAND AND WALES: Dunn, P. 200X. 2002 Survey of trout production in England and Wales. Trout News. CEFAS Weymouth Laboratory, Dorset. p. 5-7.	Trout, Atl. salmon production by region, (not by environment) 2000-2002
	CEFAS. 1999-2009. Shellfish production - Farmed shellfish production in the UK. Shellfish news. No 8-28. URL: www.cefas.co.uk/news-and-events/shellfish-news.aspx. Accessed Jan 2010.	Shellfish prod by country 1999-2008, England and Wales combined 1995-2008, some regional %ages
	European Commission. 2009. EUROSTAT Data Explorer [online]. Fisheries – Aquaculture Production. V2.2.B.9. URL: http://epp.eurostat.ec.europa.eu/portal/page/portal/statistics/search_database. Accessed Oct 29, 2009.	**NI, Wales, England:** *c.gigas* <1994-74/ *o. edulis* 1994-87 **Eng:** *m. edulis* 1994-1984/ Turbot 07, 05-00 **NI:** Atl. salmon 08-04, 97-90 **Scot:** sw *o.mykiss* 1990-79 Atl. salmon 1985-70/ Turbot 2007-2000

No Commercial Mariculture production as of 2004 in: Greenland, Isle of Man

Table A.1 Continued

Primary References: Oceania		
Country	**Source**	**Type of information**
Australia	Fisheries Victoria. 2004. Fisheries Victoria Commercial Fish Production. Information Bulletin. 1p.	Production of finfish 99/00 - 03/04, aquaculture sites by broad species
	ABARE and FRDC. 1992-2004. Australian Fisheries Statistics. Production. "Australian aquaculture production in Year by state". Australian Bureau of Agricultural and Resource Economics. Canberra. 66 p.	Multiple yearbooks, production by species by state 1992-2003
	ABARE. 1991 -2004. Australian Fisheries Statistics. Production. Australian Bureau of Agricultural and Resource Economics. Canberra. Select pages.	Multiple yearbooks, production by broad species by region 1988/89-2003/04
	ABS. 1999. Fish Account 1997. Compiled by McLennan, W. Australian Bureau of Statistics. No. 4607.0. 76 p.	Production by species and region 1989/90 – 1996/97
	Love. G., Langenkamp, D. 2003. Australian aquaculture: Industry profiles for selected species. Prepared for the Fisheries Resources Research Fund. Bureau of Agricultural and Resource Economics (ABARE). 129 p.	Production of some select species by region 2000/01, other species 95-02
	FDWA. 1990-2003. Fisheries Department of Western Australia Annual Report. Annual Report to Parliament. Various pages.	Western Australia – pearl oyster and mussel 1992-94, additional species 1990-2003
Cook Is.	SPC. 2002. Secretariat of the Pacific Community. SPC aquaculture portal - "Cook Islands". URL: www.spc.int/aquaculture/site/countries/cook_islands/index.asp. Accessed Oct 12th, 2009. SPC. 2002. Secretariat of the Pacific Community. Cultured pearl industry in the Cook Islands. URL: www.spc.int/coastfish/countries/cookislands/MMR2/Pearl.htm Accessed June 16th, 2009.	Species, production, locations
	FAO. 2009. National Fishery Sector Overview (NFSO). URL: www.fao.org/fishery/countrysector/FI-CP_CK/en Accessed Oct 12th, 2009.	Species and locations
	Tomaru, Y., Kawabata, Z., Nakano, S. 2001. Mass mortality of the Japanese pearl oyster *Pinctada fucata martensii* in relation to water temperature, chlorophyll a and phytoplankton composition. Diseases of Aquatic Organisms. 44: 61-68.	Avg. wet weight adult of pearl oysters taken from *P. fucata* (20 g) , difficulty finding wet wts
Fiji	FAO. 2008. FishStat Plus: Universal software for fishery statistical time series. "Aquaculture production 1950 – 2006". Version 2.31. FAO Fishery Information, Data and Statistics Unit.	NBR production of flathead mullet 87/88 Giant tiger prawn 1984-2004 Anadara clams 99-01
	European Commission. 2010. Eurostat Database: Aquaculture production. URL: http://epp.eurostat.ec.europa.eu/portal/page/portal/fisheries/data/database. Accessed May 5th, 2008.	NBR production of finfishes, marine fishers, crustaceans
	SPC. 2002. Secretariat of the Pacific Community. SPC aquaculture portal - "Fiji Islands". URL: www.spc.int/aquaculture/site/countries/.Accessed May 5th, 2008.	Industry history, species produced
French Polynesia	Service de la Pêche (SPE). 2006-2008. Bulletin 2006-2008. Statistiques, L'aquaculture. Bulletin [online]. URL : www.peche.pf/spip.php?rubrique200 Accessed Oct 13th, 2009	Production loup tropical, moi, crevette 1985-2008, production by location for 2008 – *some confusion over crevette vs chevrette species*
	SPC. 2002. Secretariat of the Pacific Community. SPC aquaculture portal - "French Polynesia". URL: www.spc.int/aquaculture/site/countries/french_polynesia/index.asp. Accessed Oct 12th, 2009.	Species, locations, production of 'food fish' 1998-2001 Pearl oyster 1990-2005 Penaeid prawn 1998-2001
New Caledonia	Galinie. 1989. Shrimp aquaculture in New Caledonia. *In:* Advances in Tropical Aquaculture. Tahiti Feb 20-March 4, 1989. AQUACOP IFRMER. Actes de Colloque 9: 45-50.	Sector overview, location, shrimp production NBR 1983-88
	SPC. 2002. Secretariat of the Pacific Community. SPC aquaculture portal - "New Caledonia". URL: www.spc.int/aquaculture/index.php?option=com_countries&view=country&id=11&Itemid=22. Accessed Oct 12th, 2009.	Shrimp production 1986-2004 *–other commods. produced rock oyster, rabbitfish for local market (ie. not included)*

Table A.1 Continued		
Primary References: Oceania		
Country	**Source**	**Type of information**
New Zealand	New Zealand Government. 2007. Our Blue Horizon – The Government's Commitment to Aquaculture. Ministry of Economic Development, Wellington. 47 p.	Major aquaculture areas with list of major species and proportions, est production of oyster, salmon, mussel 1983-2005
	Wassilieff, M. 'Aquaculture', Te Ara-the Encyclopedia of New Zealand [online]. Updated 26 Sept 2006. URL: www.TeAra.govt.nz/EarthSeaAndSky/HarvestingTheSea/Aquaculture/en. Accessed August 21, 2007.	Greenshell mussel, king salmon, Pacific Oyster 1983-2003 (all estimates) NBR, regional info (map)
	FAO. © 2007-2011. National Aquaculture Sector Overview. New Zealand. National Aquaculture Sector Overview Fact Sheets. Text by Jeffs, A. *In:* FAO Fisheries and Aquaculture Department [online]. Rome. Updated 1 February 2005. URL: www.fao.org/fishery/countrysector/naso_newzealand/en.Accessed August 21, 2007.	Sector history and overview, species, some locations
	Hayden, B. 1989.Aquaculture in New Zealand. Advances in Tropical Aquaculture. Paper presented at AQUACOP IFREMER. Feb 20-March 4, Tahiti. Actes de Colloque 9.:51-55	Sector history and overview, species
	NZAC. 2005. Annual Report 2004-2005. New Zealand Aquaculture Council Inc. Auckland. 12 p.	Greenshell mussel, king salmon, Pacific Oyster, Paua 2004 NBR
	NZMIC. 2007. Harvest totals. New Zealand Mussel Industry Council Ltd. [online]. URL: www.nzmic.co.nz/HarvestTotals.aspx. Accessed August 21, 2007.	Harvest totals of mussel, by region 2004-2007, locations
Papua New Guinea	NFA. 2005. Aquaculture. National Fisheries Authority, Papua New Guinea. URL: www.fisheries.gov.pg/fisheries_aquaculture.htm. Accessed 2007.	Sector status, species cultured
	FAO. 2008. FishStat Plus: Universal software for fishery statistical time series. "Aquaculture production 1950 – 2006". Version 2.31. FAO Fishery Information, Data and Statistics Unit.	Pearl oyster shells nei 2002-04 *Mangrove cupped oyster negligible (<0.5t) for all years, indication in literature that barramundi in small quantities, possibly prawn, major crocodile farmer*
Tuvalu	SPC. 2002. Secretariat of the Pacific Community. SPC aquaculture portal - "Tuvalu". URL: www.spc.int/aquaculture/site/countries/. Accessed Sept 6th, 2008.	Industry history, species produced, location
	FAO. 2008. FishStat Plus: Universal software for fishery statistical time series. "Aquaculture production 1950 – 2006". Version 2.31. FAO Fishery Information, Data and Statistics Unit.	Estimated production of milkfish 2003-2006 NBR
Vanuatu	SPC. 2002. Secretariat of the Pacific Community. SPC aquaculture portal - "Vanuatu". URL: www.spc.int/aquaculture/site/countries/. Accessed Sept 6th, 2008.	Industry history, species produced, estimates of numbers
No Commercial Mariculture production as of 2004 in: American Samoa, Kerguelen Is., Kiribati, Nauru, Niue, N. Marianas, Marshall Is., Micronesia, Palau, Pitcairn Is., Samoa, Solomon Is., Tokelau, Tonga, Wallis and Futuna Is.		

List of species included in analysis

Table A.2: Marine and brackish species included in *Sea Around Us* Project analysis, from the *Sea Around Us* database and the FAO FishstatPlus database. Italics indicate taxonomic names new to either database. Bold indicates a potential difference in the taxa included between datasets, due to classification differences. Dark grey cells in the count column indicate where broader classification nomenclature did not match up between datasets. Light grey cells in the FishStat common name category indicate where no equivalent SAUP name was located. Source: Sea Around Us Project (2009), FishBase (Froese and Pauly 2000), SeaLifeBase (Palomares and Pauly 2010).

	FishStat common name	SAUP common name	Taxon name	SAUP taxon code	Trophic code
1		***Lions-paw scallop***	*Nodipecten nodosus*	047223	2.00
2		***Purple clam***	*Soletellina diphos*	086616	2.00
3		***Equilateral venus***	*Gomphina veneriformis*	091793	2.00
4		Sturgeons, paddlefishes	Sturgeons, paddlefishes	100021	
5	Marine fishes nei	Marine fishes nei	Marine fishes not identified	100039	3.28
6		Shrimps, prawns	Shrimps, prawns	100045	3.24
7	Marine crustaceans nei	Marine crustaceans nei	Miscellaneous marine crustaceans	100047	2.7
8		Oysters	Oysters	100053	2.00
9		Mussels	Mussels	100054	2.00
10		Clams, cockles, arkshells	Clams, cockles, arkshells	100056	2.27
11	Marine molluscs nei	Marine molluscs nei	Miscellaneous marine molluscs	100058	2.27
12	Marine shells nei	Marine molluscs nei	Miscellaneous marine molluscs	100058	2.27
13		Pearls, mother-of-pearl, shells	Pearls, mother-of-pearl, shells	100081	
14	Finfishes nei	Finfishes nei	Marine fishes not identified	100139	3.23
15		Sea urchins nei	Sea-urchins and other echinoderms	100276	2.30
16	Natantian decapods nei	Natantian decapods nei	Shrimps, prawns	100345	2.65
17	Clams, etc. nei	Clams nei	Bivalvia	290004	2.23
18		Gastropods nei	Gastropoda	290006	3.06
19	Percoids nei	Perch-likes	Perciformes	300060	3.53
20	Flatfishes nei	Flatfishes	Pleuronectiformes	300061	3.57
21		Sea catfishes	Ariidae	400145	3.48
22	Groupers nei	Sea basses: groupers and fairy basslets	Serranidae	400289	3.98
23	Groupers, seabasses nei	Sea basses: groupers and fairy basslets	Serranidae	400289	3.98
24	Seabasses nei	Sea basses: groupers and fairy basslets	Serranidae	400289	3.98
25	Cobia	**Cobia**	Rachycentridae	400312	
26		Jacks and pompanos	Carangidae	400314	4.05
27		Moonfish	Menidae	400317	
28	Snappers nei	Snappers	Lutjanidae	400323	4.02
29	Snappers, jobfishes nei	Snappers	Lutjanidae	400323	4.02
30	Mullets nei	Mullets	Mugilidae	400359	2.53
31		Threadfins	Polynemidae	400361	3.62
32	Spinefeet(=Rabbitfishes) nei	Rabbitfishes	Siganidae	400413	2.11
33	**Mackerels nei**	Mackerels, tunas, bonitos	Scombridae	400416	4.26
34	Soles nei	Soles	Soleidae	400441	3.15
35		Puffers	Tetraodontidae	400448	3.50
36	**Baltic prawn**	Palaemonid shrimps	Palaemonidae	490030	3.14
37	Palaemonid shrimps nei	Palaemonid shrimps	Palaemonidae	490030	3.14
38		Penaeid shrimps	Penaeidae	490043	3.31
39	Sea mussels nei	Sea mussels nei	Mytilidae	490054	2.00
40	Scallops nei	Scallops nei	Pectinidae	490055	2.00

Table A.2: Continued					
	FishStat common name	**SAUP common name**	**Taxon name**	**SAUP taxon code**	**Trophic code**
41	**Southern Australia scallop**	Scallops nei	Pectinidae	490055	2.00
42	Cockles nei	Cockles nei	Cardiidae	490058	2.00
43	Venus clams nei	Venus clams nei	Veneridae	490060	2.00
44	Marine crabs nei	Marine crabs	Brachyura	490097	2.60
45		Pseudohemiodon	*Pseudohemiodon*	500036	
46		Paralichthys	*Paralichthys*	500048	4.14
47		Mugil	*Mugil*	500152	2.26
48		Rabbitfishes	*Siganus*	500240	2.11
49		Snappers	*Lutjanus*	500357	4.02
50		Groupers	*Epinephelus*	500366	3.84
51		Achirus	*Achirus*	500537	
52		Seabreams and porgies	*Diplodus*	500705	2.97
53		Morone	*Morone*	500737	
54		Seabreams	*Chrysoblephus*	501548	3.59
55		Scads	*Decapterus*	502102	3.63
56		Hysteronotus	*Hysteronotus*	505577	
57	Cupped oysters nei	Cupped oysters nei	*Crassostrea*	590014	2.00
58	**Gasar cupped oyster**	Cupped oysters nei	*Crassostrea*	590014	2.00
59	Abalones nei	Abalones nei	*Haliotis*	590046	2.00
60		Periwinkles nei	*Littorina*	590049	2.00
61	Stromboid conchs nei	Stromboid conchs nei	*Strombus*	590051	2.00
62		Pacifastacus	*Pacifastacus*	590060	
63	Portunus swimcrabs nei	Swims crabs	*Portunus*	590075	3.40
64		Scylla	*Scylla*	590076	
65	Palinurid spiny lobsters nei	Spiny lobsters	*Palinurus*	590082	2.70
66	Tropical spiny lobsters nei	Tropical spiny lobsters	*Panulirus*	590083	2.60
67	Metapenaeus shrimps nei	Metapenaeus shrimps nei	*Metapenaeus*	590091	2.70
68		Palaemon	*Palaemon*	590092	
69	Penaeus shrimps nei	Penaeus shrimps nei	*Penaeus*	590096	2.70
70	Horse mussels nei	Horse mussels	*Modiolus*	590116	2.00
71		Mytilus	*Mytilus*	590117	2.03
72		Chlamys	*Chlamys*	590120	2.00
73		Ark clams nei	*Arca*	590125	2.00
74	Donax clams	Donax clams	*Donax*	590128	2.00
75		Dosinia	*Dosinia*	590129	2.00
76		Ensis	*Ensis*	590130	2.00
77		Hard clams nei	*Meretrix*	590134	2.00
78		Short neck clams nei	*Paphia*	590139	2.00
79		Protothaca	*Protothaca*	590140	2.00
80	Carpet shells nei	Carpet shell	*Ruditapes*	590141	2.00
81	Razor clams nei	Razor clams nei	*Solen*	590145	2.00
82		Tapes	*Tapes*	590147	2.05
83		Pearl oyster shells nei	*Pinctada*	590160	
84		Red hind	*Epinephelus guttatus*	600015	3.88
85		Red grouper	*Epinephelus morio*	600017	3.67
86		Pollack	*Pollachius pollachius*	600034	4.15
87	European seabass	European seabass	*Dicentrarchus labrax*	600063	3.80
88	Atlantic cod	Atlantic cod	*Gadus morhua*	600069	4.01
89		**Milkfish**	*Chanos chanos*	600080	
90		Broadbarred king mackerel	*Scomberomorus semifasciatus*	600135	
91	Yellowfin tuna	Yellowfin tuna	*Thunnus albacares*	600143	4.34
92	Southern bluefin tuna	Southern bluefin tuna	*Thunnus maccoyii*	600145	3.87
93	Atlantic bluefin tuna	Northern bluefin tuna	*Thunnus thynnus*	600147	4.43
94	Spotted rose snapper	Spotted rose snapper	*Lutjanus guttatus*	600152	3.94

Table A.2: Continued

	FishStat common name	SAUP common name	Taxon name	SAUP taxon code	Trophic code
95	Russell's snapper	Russells snapper	*Lutjanus russellii*	600176	
96		Common whitefish	*Coregonus lavaretus*	600232	3.08
97	Atlantic salmon	Atlantic salmon	*Salmo salar*	600236	4.43
98	Sea trout	Sea trout	*Salmo trutta trutta*	600238	3.16
99	Rainbow trout	Rainbow trout	*Oncorhynchus mykiss*	600239	3.39
100		Pink salmon	*Oncorhynchus gorbuscha*	600240	4.19
101	Chinook(=Spring=King) salmon	Chinook salmon	*Oncorhynchus tshawytscha*	600244	4.40
102	Coho(=Silver) salmon	Coho salmon	*Oncorhynchus kisutch*	600245	4.25
103	Arctic char	Charr	*Salvelinus alpinus*	600247	4.26
104		Imperial blackfish	*Schedophilus ovalis*	600250	3.54
105		Ayu	*Plecoglossus altivelis altivelis*	600251	
106	John's snapper	Johns snapper	*Lutjanus johnii*	600264	4.18
107	Fourfinger threadfin	Fourfinger threadfin	*Eleutheronema tetradactylum*	600340	4.35
108	Common snook	Common snook	*Centropomus undecimalis*	600345	4.41
109	Barramundi (=Giant seaperch)	Barramundi	*Lates calcarifer*	600346	4.35
110	Japanese jack mackerel	Japanese jack mackerel	*Trachurus japonicus*	600366	3.4
111	Japanese amberjack	Japanese amberjack	*Seriola quinqueradiata*	600381	
112		Redbait	*Emmelichthys nitidus*	600395	3.61
113	Meagre	Meagre	*Argyrosomus regius*	600418	4.05
114		Nibe croaker	*Nibea mitsukurii*	600427	3.50
115	Large yellow croaker	Large yellow croaker	*Larimichthys croceus*	600428	3.72
116	Common dentex	Common dentex	*Dentex dentex*	600439	4.50
117	Silver seabream	Red seabream	*Pagrus major*	600445	
118	Common sole	Common sole	*Solea solea*	600525	3.17
119	Brill	Brill	*Scophthalmus rhombus*	600529	3.79
120	Flathead grey mullet	Flathead mullet	*Mugil cephalus*	600785	2.13
121	Blackspot(=red) seabream	Blackspot seabream	*Pagellus bogaraveo*	600890	3.66
122	Common pandora	Common pandora	*Pagellus erythrinus*	600893	3.52
123		Blue tang surgeonfish	*Acanthurus coeruleus*	600944	
124	Greater amberjack	Greater amberjack	*Seriola dumerili*	601005	4.50
125	Gilthead seabream	Gilthead seabream	*Sparus auratus*	601164	3.26
126	Red drum	Red drum	*Sciaenops ocellatus*	601191	4.07
127	**European flounder**	Flounder	*Platichthys flesus*	601341	3.53
128	Turbot	Turbot	*Scophthalmus maximus*	601348	3.05
129	Bastard halibut	Bastard halibut	*Paralichthys olivaceus*	601351	4.35
130	Atlantic halibut	Atlantic halibut	*Hippoglossus hippoglossus*	601371	4.53
131	Haddock	Haddock	*Melanogrammus aeglefinus*	601381	3.58
132		Crimson snapper	*Lutjanus erythropterus*	601406	
133	Mangrove red snapper	Mangrove red snapper	*Lutjanus argentimaculatus*	601407	3.90
134		Brown meagre	*Sciaena umbra*	601707	3.99
135	Sharpsnout seabream	Sharpsnout seabream	*Diplodus puntazzo*	601749	2.86
136	Sargo breams nei	White seabream	*Diplodus sargus sargus*	601753	2.98
137	White seabream	White seabream	*Diplodus sargus sargus*	601753	2.98
138	Red porgy	Common seabream	*Pagrus pagrus*	601756	3.95
139	Snubnose pompano	Snubnose pompano	*Trachinotus blochii*	601963	3.74
140		**Brown trout**	*Salmo trutta fario*	602083	
141		**Cobia**	*Rachycentron canadum*	603542	4.31
142	White-spotted spinefoot	White-spotted spinefoot	*Siganus canaliculatus*	604456	
143	Greasy grouper	Greasy grouper	*Epinephelus tauvina*	604461	4.23
144	Sobaity seabream	Sobaity seabream	*Sparus hasta*	604499	
145	Thinlip grey mullet	Thinlip mullet	*Liza ramada*	604583	
146	Japanese seabass	Japanese seaperch	*Lateolabrax japonicus*	604589	3.78

Table A.2: Continued					
	FishStat common name	**SAUP common name**	**Taxon name**	**SAUP taxon code**	**Trophic code**
147		Shoemaker spinefoot	*Siganus sutor*	604615	
148	So-iuy mullet	So-iuy mullet	*Mugil soiuy*	604791	2.49
149	Hong Kong grouper	Hong Kong grouper	*Epinephelus akaara*	605158	
150		Puntius katolo	*Puntius katolo*	605188	
151	Goldlined seabream	Goldlined seabream	*Rhabdosargus sarba*	605368	
152		Brownspotted grouper	*Epinephelus chlorostigma*	605524	3.99
153	Goldsilk seabream	Picnic seabream	*Acanthopagrus berda*	605526	3.48
154	Yellowfin seabream	Yellowfin seabream	*Acanthopagrus latus*	606356	3.15
155	Sixfinger threadfin	Sixfinger threadfin	*Polydactylus sexfilis*	606416	3.43
156	Malabar grouper	Malabar grouper	*Epinephelus malabaricus*	606439	
157		Whitespotted grouper	*Epinephelus coeruleopunctatus*	606440	
158	Orange-spotted grouper	Orange-spotted grouper	*Epinephelus coioides*	606465	3.90
159		Coral grouper	*Epinephelus corallicola*	606466	
160	Blackhead seabream	Black porgy	*Acanthopagrus schlegeli*	606531	3.24
161		Yellow grouper	*Epinephelus awoara*	607329	
162		Torafugu	*Takifugu rubripes*	608198	
163	Senegalese sole	Senegalese sole	*Solea senegalensis*	608852	3.13
164	Pacific bluefin tuna	Pacific bluefin tuna	*Thunnus orientalis*	614290	4.21
165		Lizardfish	*Synodus marchenae*	650023	
166		Paralichthys microps	*Paralichthys microps*	654963	
167	American cupped oyster	American cupped oyster	*Crassostrea virginica*	690009	2.00
168		American sea scallop	*Placopecten magellanicus*	690011	2.00
169		Atlantic bay scallop	*Argopecten irradians*	690030	2.00
170	Banana prawn	Banana prawn	*Penaeus merguiensis*	690042	3.00
171	Bear paw clam	Bear paw clam	*Hipposus hipposus*	690044	2.00
172		Black-lip pearl oyster	*Pinctada margaritifera*	690048	
173	Blood cockle	Blood cockle	*Anadara granosa*	690050	2.00
174	Blue crab	Blue crab	*Callinectes sapidus*	690052	2.60
175	Blue mussel	Blue mussel	*Mytilus edulis*	690053	2.00
176	Blue shrimp	Blue shrimp	*Penaeus stylirostris*	690054	2.70
177		Brown mussel	*Perna viridis*	690060	2.00
178	Butter clam	Butter clam	*Saxidomus giganteus*	690064	2.00
179	Caramote prawn	Caramote prawn	*Penaeus kerathurus*	690070	2.70
180	Chilean flat oyster	Chilean flat oyster	*Ostrea chilensis*	690075	2.00
181	Chilean mussel	Chilean mussel	*Mytilus chilensis*	690076	2.00
182		Chilean sea urchin	*Loxechinus albus*	690078	2.30
183	Cholga mussel	Cholga mussel	*Aulacomya ater*	690081	2.00
184	Choro mussel	Choro mussel	*Choromytilus chorus*	690082	2.00
185	Common cuttlefish	Common cuttlefish	*Sepia officinalis*	690085	3.60
186		Common octopus	*Octopus vulgaris*	690088	4.10
187	Common prawn	Common prawn	*Palaemon serratus*	690090	2.70
188	Cortez oyster	Cortez oyster	*Crassostrea corteziensis*	690094	2.00
189	European flat oyster	European flat oyster	*Ostrea edulis*	690123	2.00
190		Farrers scallop	*Chlamys farreri*	690129	2.00
191	Fleshy prawn	Fleshy prawn	*Penaeus chinensis*	690133	2.70
192	Gazami crab	Gazami crab	*Portunus trituberculatus*	690143	2.60
193	Giant clam	Giant clam	*Tridacna gigas*	690147	2.00
194	Giant tiger prawn	Giant tiger prawn	*Penaeus monodon*	690151	2.60
195	Globose clam	Globose clam	*Mactra veneriformis*	690153	2.00
196	Greasyback shrimp	Greasyback shrimp	*Metapenaeus ensis*	690155	2.00
197	Great Atlantic scallop	Great Atlantic scallop	*Pecten maximus*	690156	2.00
198	Green mussel	Green mussel	*Mytilus smaragdinus*	690160	2.00
199	Green tiger prawn	Green tiger prawn	*Penaeus semisulcatus*	690163	2.70
200	Grooved carpet shell	Grooved carpet shell	*Ruditapes decussatus*	690166	2.00
201		Half-crenated ark	*Scapharca subcrenata*	690169	2.00

Table A.2: Continued

	FishStat common name	SAUP common name	Taxon name	SAUP taxon code	Trophic code
202		Hen clam	*Mactra sachalinensis*	690176	2.10
203	Hooded oyster	Hooded oyster	*Saccostrea cucullata*	690177	2.00
204	Indian backwater oyster	Indian backwater oyster	*Crassostrea madrasensis*	690186	2.00
205	Indian white prawn	Indian white prawn	*Penaeus indicus*	690189	2.70
206	Indo-Pacific swamp crab	Indo-Pacific swamp crab	*Scylla serrata*	690190	2.80
207	Inflated ark	Inflated ark	*Scapharca broughtonii*	690191	2.00
208		Japanese abalone	*Haliotis discus*	690195	
209	Japanese carpet shell	Japanese carpet shell	*Ruditapes philippinarum*	690196	2.00
210	Japanese hard clam	Japanese hard clam	*Meretrix lusoria*	690199	2.00
211		Japanese pearl oyster	*Pinctada fucata*	690200	2.00
212	Japanese sea cucumber	Japanese sea cucumber	*Apostichopus japonicus*	690201	2.30
213	Korean mussel	Korean mussel	*Mytilus coruscus*	690218	2.00
214	Kuruma prawn	Kuruma prawn	*Penaeus japonicus*	690219	2.70
215		Lugubrious cupped oyster	*Crassostrea belcheri*	690229	2.00
216	Mangrove cupped oyster	Mangrove cupped oyster	*Crassostrea rhizophorae*	690232	2.00
217		Manila clam	*Corbicula manilensis*	690233	2.00
218	Mediterranean mussel	Mediterranean mussel	*Mytilus galloprovincialis*	690241	2.00
219	New Zealand mussel	New Zealand mussel	*Perna canaliculus*	690258	2.00
220		Noble scallop	*Chlamys nobilis*	690262	
221	Northern quahog(=Hard clam)	Northern quahog	*Mercenaria mercenaria*	690270	2.00
222	Northern white shrimp	Northern white shrimp	*Penaeus setiferus*	690272	2.70
223	Olympia flat oyster	Olympia flat oyster	*Ostrea lurida*	690279	2.00
224	Pacific calico scallop	Pacific calico scallop	*Argopecten circularis*	690282	2.00
225	Pacific cupped oyster	Pacific cupped oyster	*Crassostrea gigas*	690283	2.00
226	Pacific geoduck	Pacific geoduck	*Panopea abrupta*	690284	2.00
227	Pacific littleneck clam	Pacific littleneck clam	*Protothaca staminea*	690285	2.10
228	Penguin wing oyster	Penguin wing oyster	*Pteria penguin*	690300	2.00
229	Perlemoen abalone	Perlemoen abalone	*Haliotis midae*	690302	2.00
230	Peruvian calico scallop	Peruvian calico scallop	*Argopecten purpuratus*	690303	2.00
231		Pink conch	*Strombus gigas*	690304	2.00
232		Portuguese cupped oyster	*Crassostrea angulata*	690306	2.00
233	Pullet carpet shell	Pullet carpet shell	*Tapes pullastra*	690309	2.10
234		Purple sea urchin	*Strongylocentrotus lividus*	690311	
235	Queen scallop	Queen scallop	*Chlamys opercularis*	690314	2.10
236	Red abalone	Red abalone	*Haliotis rufescens*	690317	
237	Redtail prawn	Redtail prawn	*Penaeus penicillatus*	690328	2.70
238	Sand gaper	Sand gaper	*Mya arenaria*	690337	2.00
239		Silver-lip pearl oyster	*Pinctada maxima*	690363	
240	Slipper cupped oyster	Slipper cupped oyster	*Crassostrea iredalei*	690364	2.00
241		Small abalone	*Haliotis diversicolor*	690366	
242	Smooth mactra	Smooth mactra	*Mactra glabrata*	690368	2.00
243	South American rock mussel	South American rock mussel	*Perna perna*	690374	2.00
244	Southern white shrimp	Southern white shrimp	*Penaeus schmitti*	690382	2.70
245	Spinous spider crab	Spinous spider crab	*Maja squinado*	690387	2.30
246	Striped venus	Striped venus	*Venus (=Chamelea) gallina*	690404	2.10
247		Suminoe oyster	*Crassostrea rivularis*	690407	2.00
248		Whelk	*Buccinum undatum*	690434	3.10
249	Whiteleg shrimp	Whiteleg shrimp	*Penaeus vannamei*	690440	2.00
250	Yesso scallop	Yesso scallop	*Pecten yessoensis*	690445	2.10
251		Aequipecten opercularis	*Aequipecten opercularis*	690603	2.00
252		Cerastoderma edule	*Cerastoderma edule*	690605	2.00
253		Pullet carpet shell	*Venerupis pullastra*	690630	2.00
254		Blood arc clam	*Anadara ovalis*	690649	2.00
255	Pacific horse clam	Pacific gaper clam	*Tresus nuttallii*	690664	2.00
256	Banded carpet shell	Banded carpet shell	*Tapes rhomboides*	690675	2.00
257		Purple dye murex	*Bolinus brandaris*	690689	2.00

Table A.2: Continued

	FishStat common name	SAUP common name	Taxon name	SAUP taxon code	Trophic code
258	Warty venus	Warty venus	*Venus verrucosa*	690693	2.00
259	Oriental cyclina	Oriental cyclina	*Cyclina sinensis*	690695	2.00
260	Constricted tagelus	Constricted tagelus	*Sinonovacula constricta*	690698	2.00
261		***Mangrove oyster***	*Crassostrea tulipa*	690887	2.00
262		***Kumamoto oyster***	*Crassostrea sikamea*	690888	2.00
263		***Rock scallop***	*Crassedoma giganteum*	690889	2.00
264		Misc. Marine Fauna		888888	

Appendix B: Appendix to Chapter 3

UNEP GEO-4 scenario framework

Table B.1: Key assumptions of GEO-4 development scenario framework. Source: (UNEP 2007)

Driver category	Critical uncertainty	Fundamental assumption			
		Markets First	**Policy First**	**Security First**	**Sustainability First**
Institutional and socio-political frameworks	What is the dominant scale of decision making?	International	International	National	None
	What is the general nature and level of international cooperation?	High, but with focus on economic issues (trade)	High	Low	High
	What is the general nature and level of public participation in governance?	Low	Medium	Lowest	High
	What is the power balance between government, private and civil sector actors?	More private	More government	Government and certain private	Balanced
	What is the overall level and distribution of government investment across areas (e.g., health, education, military and R&D)?	Medium, fairly evenly distributed	Higher, more emphasis on health and education	Low, focus on military	Highest, more emphasis on health and education
	What is the general nature and level of official development assistance?	Low	Higher, increasingly as grants not loans	Lowest	Highest, increasingly as grants not loans
	To what degree is there mainstreaming of social and environmental policies?	Low, for example little or no specific climate policy, reactive policies with respect to local air pollutants	High, for example, aims at stabilization of CO_2-equicalent concentration at 650 ppmv, proactive policies on local air pollutants	Lowest, for example, little or no specific climate policy, reactive policies with respect to local air pollutants	Highest, for example, aims at stabilization of CO_2-equivalent concentration at 550 ppmv, proactive policies on local air pollutants
Demographics	What actions are taken related to international migration?	Open borders	Fairly open borders	Closed borders	Open borders
	How many children do women want to have when the choice is theirs to make?	Continued trend towards fewer births as income rises	Accelerated trend	Slowing trend	Accelerated trend
Economic demand, markets and trade	What actions are taken related to the openness of international markets?	Move to increased openness, with few controls	Increasingly open, with some embodiment of fair trade principles	Move towards protectionism	Increasingly open, with strong embodiment of fair trade principles
	To what degree is there an emphasis on sectoral specialization vs. diversification in the economy?	Specialized	Balanced	Diverse, but with emphasis on sectors of interest to governments and powerful private sector actors	Diverse
	How much do people chose to work in the informal economy?	Most work in formal economy	Most work in formal economy	Large underground economies	Variable by region and societal groups
	What is the general level and emphasis of government intervention in policy?	Low, efficient markets	High, efficient but also fair markets	Variable by region and sector	Medium, greater emphasis on fairness of markets

Table B.1: Continued					
Driver category	**Critical uncertainty**	**Fundamental assumption**			
		Markets First	**Policy First**	**Security First**	**Sustainability First**
Scientific and technological innovation	What are the levels, sources, and emphases of R&D investment?	High, primarily private or by government at behest of private sector, for profit	High, primarily government Benign, but still with eye on profit	Variable, government and certain private sector actors Military/ security	High, from range of sources Benign, appropriate
	What is the emphasis in terms of energy technologies?	Focus on economic efficiency	Focus on general efficiency and environmental impact	Emphasis on security of supply	Focus on general efficiency, environmental impact
	What is done with respect to the access and availability of new technologies?	What you can pay for, primarily through trade	Promotion of technology transfer and diffusion	Closely guarded	Promotion of technology transfer and diffusion, and encouragement of open source technologies
Value systems	What actions are taken related to cultural homogenization vis-à-vis diversity?	Little overt action	Little overt action	Diverse, tending toward xenophobia	Efforts to maintain diversity and tolerance
	What is the emphasis on individualism vis-à-vis the community?	Individual	More community	Individual	Community
	What is the relative rank of conflicting priorities in fisheries?	Profits	Balance between profits, total catch and jobs	Total catch	Focus on ecosystem restoration, but also emphasis on jobs and landings
	What are the key priorities with regard to protected areas?	"Sustainable use" emphasizing tourism development and some genetic resource protection	Species conservation and ecosystem services Maintenance, then sustainable use, include benefit sharing	Tourism development, some genetic resource protection	Sustainable use, including benefit sharing, then ecosystem services maintenance and species conservation
	How do resource demands shift, independent of changing process and income?	Follow traditional patterns	Follow traditional patterns for most resources, but some relative reduction in water use	Follow traditional patterns	Slower uptake of meat consumption, energy use, water use and other resource use with rising income

Sea Around Us mariculture scenario framework

Table B.2: Key assumptions underlying the mariculture development scenario framework. The five driver categories remain unchanged from the original. Critical uncertainties with a (*) are closely adapted from GEO-4. Fundamental assumptions are either adapted directly from the GEO-4 (*) or developed based on the literature and expert opinion.

Driver Category	Critical uncertainty	Fundamental assumption			
		Markets First	**Policy First**	**Security First**	**Sustainability First**
Institutional and socio-political frameworks	What is the balance of power in mariculture production between government, private, and civil sector actors?*	More private	More government	Government and some private	Balanced
	What is the overall level and distribution of general investment in sustainable development training and education in the aquaculture sector?	Intermediate, emphasis on those able to pay for it	Higher, focus on major actors and main issues	Low, knowledge is closely guarded by wealthy government and private actors	Highest, efforts made to invest in and broadly disseminate knowledge, include less powerful actors
	What is the overall level and distribution of investment in improving information systems critical to effective sustainable development?	Low, private-sector efforts are profit-driven	Highest, government-led efforts seek to improve information for organization, assessment, monitoring, and enforcement	Lowest, privacy restrictions increase and general international cooperation decreases	High, widespread recognition of the benefits of detailed, ecosystem-oriented information for use in sustainable development policy
	To what degree is there mainstreaming of social and environmental policies in mariculture practices?*	Intermediate, efforts made to improve efficiency, eco-labelling, certification, niche-marketing made only where economically profitable	High, policy reforms contain stronger and more widespread social and environmental considerations, but with profit in mind	Lowest, policies are reactive and control-oriented	Highest, strong collaborative support at all levels for major policy reforms
Demographics	How fast is the fish-consuming global population growing?*	Intermediate trend	Accelerated trend	Slowing trend	Accelerated trend
	What is the relative influence of the growing Asian middle class on the mariculture production market?	Highest, demand in Asia increases for diversified, high-value seafood	High, some market controls mean demand effects are dampened	Intermediate, market controlled by the interests of the wealthy and powerful	High, demand in Asia increases for diversified, increasingly sustainable, high-value seafood
Economic demand, markets and trade	What is the dominant global trend in demand for seafood relative to 2004?	Rapidly increasing	Increasing	Slightly decreasing	Decreasing
	What is the level of openness in international markets?*	Move to increased openness, with few controls	Increasingly open, with some embodiment of fair trade principles	Move towards protectionism	Increasingly open, with strong embodiment of fair trade principles
	To what degree is there an emphasis on operational and market specialization vs. diversification in aquaculture?*	Tendency towards operational specialization and market diversification	More balanced	Diverse, emphasis on sectors of interest to government and powerful private actors	Diverse, increase in efforts to develop and diversify viable export markets for lower impact species

Table B.2: Continued					
Driver Category	**Critical uncertainty**	**Fundamental assumption**			
		Markets First	**Policy First**	**Security First**	**Sustainability First**
Scientific and technological innovation	What is the focus of technological and research investment in production innovations?*	Focus on economic efficiency - improving cost-effective use of resources, increasing yield, quality, safety, and consistency of high-value species	Focus on general efficiency and environmental impact - improving information systems as well as waste and energy efficiency, primarily for high-value but also for some lower-value, more sustainably - raised species	Emphasis on security of supply - reducing reliance on imports, expanding and improving yield and production efficiency of carnivorous high-value species	Focus on general efficiency and environmental impact - improved feed conversion, artificial breeding, yield and energy efficiency, developing higher-value niche markets for organic production, increasing and diversifying yield and quality of lower-impact species
	What is the general level of reliance on wild fisheries resources for production?	Lower, significant widespread private investments made to reduce wild-capture feed and seed inefficiencies and constraints to sector growth	Intermediate, some efforts to reduce reliance made by countries with the financial or technological ability to do so	Highest, increase in the domestic use of wild-capture sources for fishmeals and oils for feed, technologies that reduce reliance closely guarded	Lowest, significant widespread collaborative investments made to reduce wild-capture feed and seed use to increase efficiency and reduce environmental impacts
Value systems	What is the relative rank of conflicting priorities in mariculture?*	Profits	Balance between profits, total production, and jobs	Total production	Focus on ecosystem restoration, but also emphasis on jobs and production
	What is the interaction of mariculture vis-à-vis protected areas?*	Focus on profitable aspects of protection, "Sustainable use", emphasis on tourism development, carbon sequestration, some genetic resource protection	Benefit sharing, improved balance between species and ecosystem services conservation, maintenance, and sustainable use	More antagonistic, share of benefits favours the powerful, tourism development, some genetic resource protection	Cooperative, sustainable use with benefit sharing, followed by maintenance of ecosystem services and species conservation
	What is the general level emphasis placed on the commoditization of ecosystem services?	Highest, sustainability targets are profit-driven	High, recognition of commoditization as a conservation tool while still generating profit	Low, commoditization only where total production is not adversely affected	Intermediate, commoditization tempered by efforts to minimize marginalization