Environmental Tradeoffs Between Aquaculture and Capture Fisheries

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Abstract. The incorporation of fisheries commodities into the International Food Policy Research Institute’s (IFPRI) International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT) model suggests that demand for fisheries products will rise faster than supply over the next two decades, and that fishery commodity prices will rise relative to other foods. As a consequence, maintaining the integrity of fisheries resources will continue to grow in importance as a policy issue. The growth of aquaculture can affect the health of capture fisheries through several pathways. Its potentially negative impacts include habitat degradation, escaped farmed species, and the demand for wild-caught feed inputs. Evidence from existing studies is synthesized on the policy issues arising from the environmental interfaces between the two activities. IMPACT modeling is discussed and results of various scenarios are presented, addressing aquaculture’s potential to ease pressure on wild fisheries through price-induced supply response. Capture fisheries production in a slow aquaculture growth scenario is approximately 3 million metric tons higher than in a rapid aquaculture growth scenario. However, fishmeal and fish oil prices rise by nearly 50% under the rapid aquaculture growth scenario, indicating that the growth of high-value aquaculture has the potential to influence pressure on reduction stocks, barring technical change.

Keywords: Aquaculture, fisheries, environment, projections to 2020, fishmeal.

1. INTRODUCTION

Capture fisheries production has stalled during the past decade, while aquaculture production has boomed. During the 1990s, aquaculture accounted for 80% of the growth in fisheries production for human consumption; its importance as a source of growth will only increase with coming years. Aquaculture is growing in importance as a food source, as an income source, as a source of export revenue for developing countries, and as a consumer of resources. Combined, aquaculture and capture fisheries provide about 20% of the world’s animal protein, employ 36 million people directly and millions more indirectly (FAO 2000), and affect land and water use on every continent and in every ocean.

The growth of aquaculture production is a necessary element of meeting higher demand over the next several decades; however, the expansion and intensification of aquaculture has also created environmental conflicts with other sectors, including capture fisheries themselves. Intensive aquaculture in particular has been highlighted as particularly threatening to some wild fishery stocks through the degradation of natural resources, escaped farmed species, and the demand for wild-caught feed inputs (Naylor et al. 2000). These concerns and real negative feedbacks will only increase in the absence of mitigating technical change or regulation.

On the other hand, the addition of supply of fisheries products from aquaculture could place downward pressure on prices if farmed products and wild products behave as substitutes, thus lowering incentives to apply fishing effort. In examining this relationship, the International Food Policy Research Institute’s (IFPRI) International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT) model can be helpful, as it allows for price linkages between different commodities and regions, thus permitting quantitative estimates of interaction among fisheries sectors and other sectors (Rosegrant et al. 2001; Delgado et al. 2002). By modeling substitution across commodities both on the demand and the supply side, it is possible to examine the possible effects of aquaculture production on capture production. IMPACT modeling also includes endogenous determination of fishmeal and fish oil demand, thus allowing exploration of how aquaculture’s growth may impact prices of these feed inputs. As understanding grows of the dynamics of the environmental effects of aquaculture, the approach used here will also be useful in modeling the negative environmental feedbacks between the sectors. Coming to grips with the order of magnitude of tradeoffs between the aquaculture and capture fisheries will be crucial to reasoned policymaking over the next several decades.
2. NEGATIVE FEEDBACKS FROM AQUACULTURE TO CAPTURE FISHERIES

The capture fisheries sector is one of the last large-scale human activities that can be classified under the rubric of “hunting and gathering.” As such, it is almost by definition fundamentally dependent on the natural environment. There is clearly a limit to the capacity of the world’s oceans to supply wild stocks of fish, and the production plateau witnessed recently indicates that fisheries may be approaching this limit. After decades of steady growth, total capture fisheries production has hovered near 95 million metric tons (mmt) for over a decade. As a result of sustained, increasing fishing pressure, most stocks of wild fish today are classified as fully exploited, and an increasing number are overexploited, in decline, or in recovery (FAO 2000). History holds numerous examples of fishery collapses, including the California sardine fishery collapse of the 1940s and the recent decline in Northwest Atlantic groundfish stocks. Few expect significant jumps in global production from wild fisheries in the future.

Meanwhile, aquaculture has taken up the slack in production. Global aquaculture production has grown at nearly 10% per year since 1973, rising from below a 7% share in total seafood production to over 30% today. This astonishing rate of growth, while largely due to the expansion of low-value freshwater fish culture in Asia, has also included large-scale, high-value aquaculture using intensive production techniques. Shrimp farming in Southeast Asia and Latin America, for example, has become a major source of export revenue for developing countries in those regions. Aquaculture has emerged as a widely promoted strategy for development at a regional level and for food and income production at a household level. Rapid growth in aquaculture production is projected to continue under the IMPACT baseline scenario, nearly doubling at a global level by 2020. However, the growth of the industry has spawned a number of significant environmental concerns among academics, policymakers, advocates, and stakeholders. Several of these concerns impinge directly on the health of capture fisheries resources, although few quantitative estimates exist of diminished productive capacity.

2.1 Direct conflicts

One interface between aquaculture and wild stocks of fish comes from the escape of cultured species into the wild. For instance, escaped farmed tilapia, which thrive in disturbed habitat where native species are already at risk, have established themselves in waterways in the United States, Asia, Australia, and Africa. Aside from the risks of direct predation on native species or competition for food and habitat, escaped farmed fish may threaten the genetic pools of wild organisms through interbreeding. Studies have shown instances of escaped farmed Atlantic salmon—which number in the hundreds of thousands every year—successfully reproducing, establishing themselves in the wild, mingling with wild Atlantic salmon stocks, and even altering the genetic makeup of these stocks (Clifford et al. 1998). Traits bred into farmed fish are often different from those conferring reproductive fitness in the wild, and interbreeding between escaped farmed fish and wild fish may result in the loss of important local adaptations. Risk is greatest for small populations that are already threatened. By contrast, a report from the U.S. National Marine Fisheries Service (Nash 2001) argues that escapes of Atlantic salmon in the Pacific Northwest hold little or no risk to native Pacific salmon populations, as they cannot interbreed and are poor competitors for resources.

Though concerns exist over the possible spread of disease from farmed populations to wild populations, the primary direction of pathogen flow is from wild stocks to farmed stocks (often through the use of wild broodstock and larvae). The magnitude of disease risk for wild fish is unclear, as little is known of harm to wild stocks caused by diseases originating on farms. Salmon hatcheries in the Pacific Northwest, for instance, have similar disease problems as those found in aquaculture, and release orders of magnitude more fish into the wild, but adverse disease effects on wild populations are low (Nash 2001).

Concerns over escaped species are likely to intensify in coming years as aquaculture’s scope increases, but particular attention will be focused on the problem as genetically modified fish are developed for aquaculture operations around the world. Although no transgenic fish have yet been approved for commercialization, both developed and developing countries have tested transgenic farmed species ranging from shellfish to freshwater fish to marine fish (FAO 2000). In addition to the potential for harm to wild stocks that exist with other escaped farmed species, the genetic modification of organisms introduces considerable uncertainty. Simulations have demonstrated the theoretical possibility of transgenic fish introducing a “Trojan Horse” gene that entirely wipes out a native population (Muir and Howard 1999). Such risks would be eliminated if a reliable means were found of rendering all farmed fish incapable of reproduction. In the United States, regulatory power over the approval of transgenic fish is held by the Food and Drug Administration, which may not have the institutional capacity required to adequately assess environmental impacts. Those involved in policy debates over introduction of
transgenic aquatic species will face the difficult task of weighing the benefits conferred by commercially beneficial traits against the risks of introducing species with these traits into an ecosystem.

The construction of ponds or pens for aquaculture may involve the disturbance or destruction of productive fisheries habitat. Effluent from ponds can contribute to eutrophication of downstream waters, and waste from marine culture can harm benthic communities, though the latter effect is locally restricted. In many cases, aquaculture may be no worse than other land-based activities in its effects on habitat, especially terrestrial agriculture. Because aquaculture is a relatively new activity in many areas, more attention tends to be focused on its effects. In some cases, however, aquaculture development is the direct cause of habitat degradation. A notable example is the clearing of mangrove forests to make way for shrimp ponds. Mangroves provide nursery habitat for numerous species of fish and shellfish that are economically important to wild fisheries and artisanal fishing communities. Since mangroves also provide water filtration services, their removal has impacts on downstream fish habitats such as coral reefs. Naylor et al. (2000) estimate that over 100 kg of fish within mangrove ecosystems are lost for every hectare of mangroves converted; they further estimate that each kilogram of shrimp produced from coastal aquaculture in former mangrove forests results in a loss of over 400g of wild fish.

2.2 Demand for wild-caught feed inputs

The use of fishmeal and fish oil in intensive aquaculture has generated much controversy and attention in recent years. Rapidly increasing demand by aquaculture for these feed inputs has led to concern that the farming of carnivorous and omnivorous fish will place pressure on the wild pelagic stocks from which fishmeal and fish oil are derived. As Asche and Tvetneras (2000) argue, substitution away from fishmeal in terrestrial livestock production has compensated for increased demand from aquaculture, with no net effect on the price of fishmeal. However, as aquaculture grows, a greater share of demand for fishmeal and fish oil will become relatively less elastic, raising the possibility that aquaculture may in the long run drive up the prices of these inputs. The price spike following the 1997-98 El Niño event, and the high share of aquaculture in fishmeal demand during that period, support this view.

Feed demand for fishmeal and fish oil is endogenously determined in the IMPACT model, allowing for an examination of aquaculture’s potential effect on prices and production. The following section includes a description of the methodology used and the results obtained with IMPACT. A fuller discussion of the issue is given in Wada et al. 2002.

3. ESTIMATING AQUACULTURE’S PRICE-MEDIATED IMPACT ON WILD FISHERIES

Not all potential impacts of aquaculture on capture fisheries are negative, however. Aquaculture will be the most important source of supply growth in fisheries products in the future, and as such has been regarded as a possible savior for overburdened and overexploited wild stocks of fish. Of course, the extent to which this is true depends upon a large number of assumptions and uncertainties. The following section presents the results of modeling under a set of assumptions that, while they do not perfectly represent many aspects of fisheries, may serve to frame the issue in a reasonable manner and set the stage for more refined global modeling.

3.1 Assumptions and parameter specifications

Determining production patterns for fisheries commodities requires the consideration of a wide range of factors, including substitution with other commodities; determinants of consumption growth including population and income; and the prices for each commodity that equilibrate supply, demand, and trade for each region under consideration. The IMPACT model is thus a useful tool to explore the general magnitude of price-induced shifts in the composition of fisheries supply at the global and regional levels. Fisheries commodities were aggregated into 10 categories and integrated into the IMPACT model, which covers 36 country groups and 22 non-fish food commodities in all.

For modeling purposes, commodities within a group should have similar price substitution parameters, and demand for the commodities should respond in similar ways to changes in price and income. Categories should be comprised of products that are fairly homogeneous in value. Finally, it is important to create categories that are meaningful and identifiable to those without specialized knowledge of fisheries. Incorporating fisheries
products into a model such as IMPACT, however, necessitates that the number of commodity categories be restricted, as each additional commodity requires the specification of hundreds of parameters.

A crucial assumption made in the IMPACT model is the equivalence on the demand side of fisheries products from capture and fisheries products from aquaculture. This assumption inevitably overstates the extent to which aquaculture-derived and capture-derived products behave as substitutes. There is empirical evidence for substitute relationships in the literature (Bene et al. 2000; Clayton and Gordon 1999), but the overall market relationship between aquaculture-derived and capture-derived fisheries products is unpredictable (Pascoe et al. 1999). The assumption of substitutability provides a favorable set of circumstances for aquaculture production to drive down capture production through price effects (Anderson 1985, Ye and Beddington 1996).

Price response is mediated through supply elasticities, which are specified to be higher in aquaculture than in capture fisheries. Few empirical studies of supply elasticities in capture fisheries exist due to inherent estimation difficulties; Pascoe and Mardle (1999) show generally inelastic supply in North Sea fisheries. Resource and regulatory constraints limit positive production responses to higher prices; subsidies and slow movement of resources out of the capture fisheries sector in many countries indicate that price responsiveness in the other direction may be fairly low as well. Consequently, supply elasticities for capture fisheries are set to be fairly low. By contrast, supply elasticities for aquaculture-derived commodities in the IMPACT model are generally more than double those for capture-derived commodities, reflecting the greater capacity for expansion and intensification of production (and, conversely, the greater ability for the sector to contract) in aquaculture. Other modeling efforts have made similar supply elasticity assumptions (Chan et al. 2002).

In the model, multiple sectors compete for fishmeal and fish oil consumption. Demand is determined with a series of regionally and sectorally specified feed conversion ratios mediated through feed demand elasticities. This relationship allows the composition of demand for fishmeal and fish oil to change in response to price changes, with sectors having a more rigid demand for these inputs consuming a larger share if prices rise.

3.2 Differences among various scenarios

Under the IMPACT baseline scenario, aquaculture production grows to 2020 at an average annual rate of 2.8%, nearly doubling from 1997-2020. Capture production, by contrast, grows much more slowly, at an average annual rate of 0.7%. Prices for all capture fisheries commodities for human consumption rise 4-16%. The sensitivity of capture fisheries production to varying degrees of growth in the aquaculture sector can be illustrated through scenarios using different assumptions for the exogenous rate of technical change in aquaculture. Figure 1 shows the different pathways of capture production followed under a rapid aquaculture growth scenario, with exogenous growth rates 50% higher than in the baseline, and a slower aquaculture growth scenario, with growth rates 50% lower than in the baseline. The supply response induced by relatively lower prices under the rapid aquaculture growth scenario is on the order of 4% of total global production, with about 40% of the difference accounted for by China. Although level of production is not an ideal proxy for effort or fishing pressure, it does give an indication of the extent to which resources flow in or out of capture fisheries in response to various factors. Table 1 shows global capture fisheries production under these IMPACT scenarios.

Price movements in large part determine incentives to apply fishing effort. Table 2 shows projected price changes for fisheries commodities under different scenarios. Under the rapid aquaculture growth scenario, prices for fisheries commodities actually decline; under the slow growth scenario, prices rise 19-25% over the projection period. By far the largest price rises occur under an extreme scenario (not shown) where capture fisheries production declines significantly, resulting in price increases ranging from 26-70% for the commodities modeled. IMPACT projections show higher real prices by 2020 (18% higher than 1997 levels) for fishmeal and oil under the baseline scenario, and much higher prices (approximately 50% higher) under a scenario with faster growth in aquaculture. A scenario with rapid efficiency improvements in the utilization of fishmeal and oil results, however, in real price declines for these commodities. Feed efficiency improvement under this scenario occurs at a rate double that in the baseline, diminishing fishmeal and fish oil demand from aquaculture and causing price declines of 16% and 5%, respectively.

4. IMPLICATIONS OF IMPACT SCENARIOS FOR ENVIRONMENTAL ISSUES

In the context of policy discussions of fisheries and aquaculture development, it is important to determine general orders of magnitude for environmental impacts. Although there is a significant price differential.
between the faster and slower aquaculture growth scenarios, the difference in capture production between the two scenarios is fairly small. If assumptions about supply elasticities in the capture sector are reasonable, this indicates that the pathway followed by aquaculture will have only a modest effect on the amount of fishing pressure applied in the near future, even under unrealistically liberal assumptions about the interchangeability of products from capture and aquaculture. Aquaculture’s growth does have a substantial impact on prices of seafood commodities, however, and it is possible that significantly higher prices could induce a larger response in capture fishing effort than is apparent in the IMPACT model. More likely, a larger price response would come from increased aquaculture development, since capacity for long-term growth in the majority of capture fisheries is extremely limited. It should be pointed out that no global estimates exist of direct harm to capture production by externalities from aquaculture. Of course, there are important environmental impacts that production totals cannot capture, especially effects on biodiversity and habitat modification. When relationships can be quantified, however, global modeling of the kind presented here can be useful in establishing a context for debates over the future of capture fisheries and aquaculture. Other scenarios that explicitly model environmental feedbacks between culture and capture can be run with new assumptions.

A large issue in aquaculture over the coming years will be the rate at which carnivorous aquaculture is able to substitute away from fishmeal and fish oil. Although faster aquaculture growth induces lower prices and therefore lower capture fisheries production, this scenario also induces higher prices for fishmeal and fish oil. Rapid growth in high-value finfish and crustacean culture has the capacity to cause increases in demand for these feed inputs. Relatively elastic feed demand elasticities in the terrestrial livestock sector allow for substitution away to vegetable meals, but not enough to keep prices from rising (up to 50% higher in the faster aquaculture growth scenario). These large price increases demonstrate the importance of technological change in aquaculture’s impact on reduction fish stocks. Production of fishmeal is 14% higher under the baseline scenario than under the feed efficiency scenario, and 26% higher under the rapid aquaculture growth scenario; these production increases are significant considering the slow growth in fishmeal production over the past two decades. However, the price increases are not large enough to significantly dampen production of aquaculture commodities, nor are the lower feed prices under the technological change scenario sufficient to significantly boost aquaculture production. Global production from aquaculture is only 1-2% higher than the baseline under the feed efficiency scenario.
5. FIGURES

Figure 1. Projected total capture fisheries production of food fish under differing scenarios of aquaculture production growth.

Notes: “Food fish” excludes reduction fish, aquatic mammals, amphibians, and reptiles. See Table 2 for scenario definitions.

<table>
<thead>
<tr>
<th>Global production ( '000 mt)</th>
<th>Share of total production</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline</td>
<td>76,515</td>
</tr>
<tr>
<td>Slower aquaculture growth</td>
<td>77,889</td>
</tr>
<tr>
<td>Faster aquaculture growth</td>
<td>74,998</td>
</tr>
</tbody>
</table>

Table 1. Projected capture fisheries production of food fish, 2020, under IMPACT scenarios.

Notes: “Food fish” excludes reduction fish, aquatic mammals, amphibians, and reptiles. See Table 2 for scenario definitions.
Table 2. Projected change in real price of fisheries commodities under IMPACT scenarios, 1997-2020

<table>
<thead>
<tr>
<th>Commodity</th>
<th>Baseline</th>
<th>Slower aquaculture growth</th>
<th>Faster aquaculture growth</th>
<th>Fishmeal and oil efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>High-value finfish</td>
<td>+15</td>
<td>+19</td>
<td>+9</td>
<td>+14</td>
</tr>
<tr>
<td>Low-value food fish</td>
<td>+6</td>
<td>+25</td>
<td>-12</td>
<td>+5</td>
</tr>
<tr>
<td>Crustaceans</td>
<td>+16</td>
<td>+26</td>
<td>+4</td>
<td>+15</td>
</tr>
<tr>
<td>Mollusks</td>
<td>+4</td>
<td>+25</td>
<td>-16</td>
<td>+3</td>
</tr>
<tr>
<td>Fishmeal</td>
<td>+18</td>
<td>+0</td>
<td>+42</td>
<td>-16</td>
</tr>
<tr>
<td>Fish oil</td>
<td>+18</td>
<td>-4</td>
<td>+50</td>
<td>-5</td>
</tr>
</tbody>
</table>

Notes: See Delgado et al. (2002) for details on commodity aggregations. “Slower aquaculture growth”: production growth trends (not including supply response to price change) for all aquaculture commodities decreased by 50% relative to baseline. “Faster aquaculture growth”: production growth trends (not including supply response to price change) for all aquaculture commodities increased by 50% relative to baseline. “Fishmeal and oil efficiency”: Feed conversion efficiency for fishmeal and oil improves at a rate double to that specified in baseline.

6. REFERENCES


Ye, Yimin and John R. Beddington, Bioeconomic interactions between the capture fishery and aquaculture, Marine Resource Economics, 11(2), 105-123, 1996.