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Fish as food: aquaculture's contribution

Ecological and economic impacts and contributions of fish farming and capture fisheries

• *by James H. Tidwell & Geoff L. Allan*

Historically, the oceans were considered limitless and thought to harbour enough fish to feed an ever-increasing human population. However, the demands of a growing population, particularly in poorer countries, now far outstrip the sustainable yield of the seas. At the same time as fishing has become more industrialised, and wild fish stocks increasingly depleted, aquaculture production—fish and shellfish farming—has grown rapidly to address the shortfalls in capture fisheries. But aquaculture has come under intense scrutiny and criticism as environmentalists fear that it could cause significant environmental problems and further impact wild species that are already threatened. Indeed, both capture fisheries and aquaculture must have environmental costs—all human activities of significant scale do—but it is necessary to fairly evaluate and compare the ecological and economic impact of both. In fact, a thorough analysis shows that the ecological threat of aquaculture is much lower than continuing to supply the majority of fish protein from wild capture.

Fish is a vital source of food for people. It is man's most important single source of high-quality protein, providing ~16% of the animal protein consumed by the world's population, according to the Food and Agriculture Organisation (FAO) of the United Nations (1997). It is a particularly important protein source in regions where livestock is relatively scarce—fish supplies <10% of animal protein consumed in North America and Europe, but 17% in Africa, 26% in Asia and 22% in China (FAO, 2000). The FAO estimates that about one billion people world-wide rely on fish as their primary source of animal protein (FAO, 2000).

Fish also has substantial social and economic importance. The FAO estimates the value of fish traded internationally to be US$ 51 billion per annum (FAO, 2000). Over 36 million people are employed directly through fishing and aquaculture (FAO, 2000), and as many as 200 million people derive direct and indirect income from fish (Garcia and Newton, 1997). Consumption of food fish is increasing, having risen from 40 million tonnes in 1970 to 86 million tonnes in 1998 (FAO, 2000), and is expected to reach 110 million tonnes by 2010 (FAO, 1999). Increases in per capita consumption account for only a small portion; it is the growing human population in many countries in Asia, Africa and South America that is primarily responsible for this steadily growing demand for food fish. These data illustrate that a consistent source of fish is essential for the nutritional and financial health of a large segment of the world's population.

Today, fish is the only important food source that is still primarily gathered from the wild rather than farmed—with marine capture historically accounting for >80% of the world's fish supply. Total landings from marine fisheries increased ~5-fold in the 40-year period from 1950 to 1990 (Mace, 1997). More recently, however, capture fisheries have not been able to keep pace with growing demand, and many marine fisheries have already been over-fished. In the period 1990–1997, fish consumption increased by 31% while the supply from marine capture fisheries increased by only 9% (FAO, 1999). This has intensified the pressure on the harvesters, which has translated into increased pressures on, and over-fishing of, many commercial fisheries. Nearly half of the known ocean fisheries are completely exploited (FAO, 1999), and 70% are in need of urgent management (MacLennan, 1995).

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As fisheries become depleted and fish get harder to catch, many fishermen and governments have responded with investments in equipment and technology to fish longer, harder, and farther away from their home ports. These efforts have resulted in what is essentially an 'arms race' within the marine fishing industry (MacLennan, 1995). Radio and satellite navigation allows fishermen to better locate fishing grounds, while new fish-aggregating devices intensify the harvests. These changes put immense pressure on fish stocks and leave fewer regions out of reach so that fish can reproduce unmolested, thus exacerbating the effects of over-harvesting.

Capture fisheries have advanced to the point where newly discovered fish populations can be put under severe stress more quickly than regulators can collect needed biological data and impose catch limitations. Based on the current assessment of overexploitation of many fish stocks, and overcapacity and

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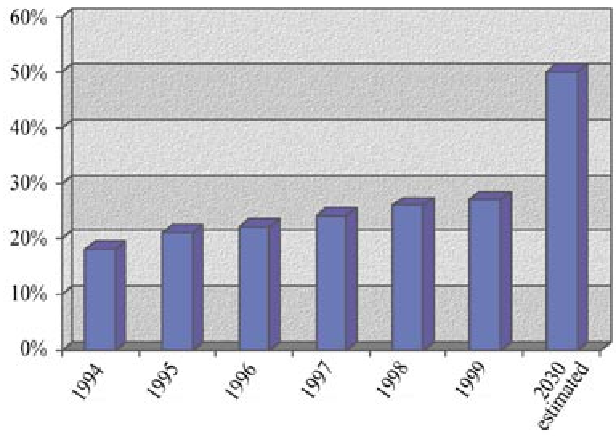

Fig. 1. The percentage of total food fish supplied by aquaculture.

overcapitalisation of many fishing fleets, Mace (1997) concluded that many capture fisheries would probably not be commercially viable without significant government subsidies. However, the private and public investment in increased infrastructure creates a financial inertia that makes it more difficult to reduce the pressure on fisheries (Speer, 1995).

Consumer tastes in the First World have largely contributed to the problem. Increasing demand for top predators, such as swordfish or tuna, has put severe pressure on existing stocks. The average size of fish caught for some species has dropped until there is now a significant need to impose minimum size limits, or capture moratoria, to allow these and other species to reach reproductive age and size before being removed from the population. The hunt for certain species also affects non-target species through their inadvertent capture, known as 'by-catch'. Long-line fishing for swordfish and other billfishes may significantly diminish the populations of many shark species, which are known to have slow reproductive rates and thereby slow recovery rates. Trawling technologies also capture a large amount of by-catch, known as 'trash fish'. Alverson *et al.* (1994)) estimated that ocean fishing results in ~28.7 million tonnes of by-catch annually, most of which is simply discarded. These figures are very likely to be low estimates of total wastage, as by-catch figures are often under-reported, and statistics do not include fish lost to spoilage, undetected mortality under the surface and ghost fishing through lost equipment that continues to catch fish. For certain shrimp species, the by-catch is often composed of a high percentage of juveniles of commercially important species, compounding the impact on both present and future fisheries production. Nance and Scott-Denton (1997), when analysing a 5-year survey of trawling operations in the Gulf of Mexico, found that only 16% of the total catch was commercially valuable shrimp, while 68% of the total catch was unintended by-catch, mostly juvenile finfish. In some areas of the Gulf of Mexico, it is estimated that for every 1 kg of shrimp harvested, 10 kg of other species are caught and discarded. High-profile examples of by-catch conflicts, such as the capture of sea turtles by shrimp trawls and of dolphins by purse-seines targeting tuna, have drawn severe criticism from environmental groups and consumers. But it is consumer demand that has fuelled this conflict, as tuna and shrimp are the species most demanded in developed countries.

To meet the ever-increasing demand for fish, aquaculture has expanded very rapidly and is now the fastest growing food-producing industry in the world. FAO (2000) estimates that by 2030, over half of the fish consumed by the world's people will be produced by aquaculture (Figure 1). Total aquaculture production increased from 10 million tonnes of fish in 1984 to 38 million tonnes in 1998 (FAO, 2000), and a growth rate of 11% per year has aquaculture on a pace to surpass beef production by 2010. Not only is the total amount of fish being produced important, but also how and where it is produced. While 80% of cattle is raised in industrialised nations, fish farming has been growing almost six times faster in developing countries than in developed countries. The FAO states that 'As an inexpensive source of a highly nutritious animal protein, aquaculture has become an important factor for improving food security, raising nutritional standards, and alleviating poverty, particularly in the world's poorest countries'. Indeed, in those areas where the need is greatest, the contribution of fish and shrimp farming is expected to increase. For instance, the FAO estimates that small-scale aquaculture production in Africa will significantly increase by 2010; in fact, fish and shrimp production in Africa has already grown by ~400% between 1984 (37 000 tonnes) and 1998 (189 000 tonnes).

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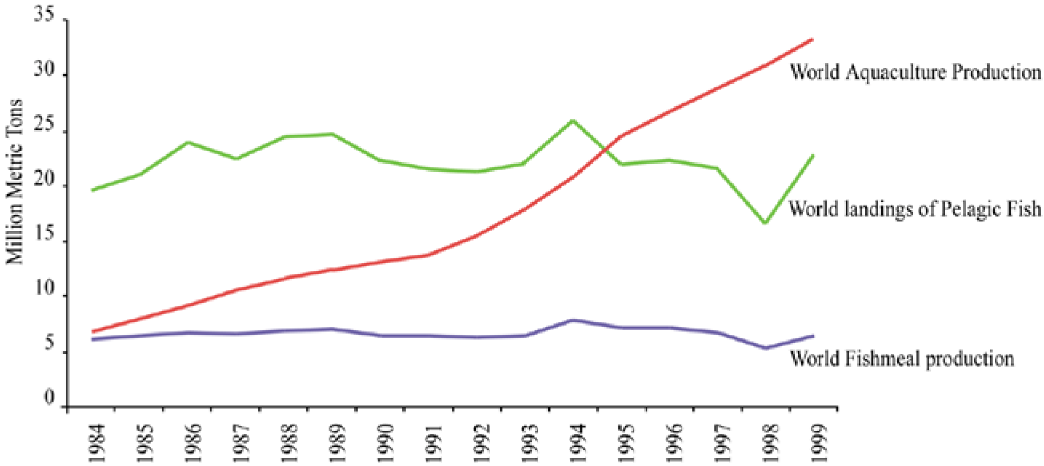

Fig. 2. The relationship between aquaculture production, pelagic fish landings and fishmeal production from 1984 to 2000 based on FAO data.

Rapid growth of aquaculture has led, in some cases, to environmental problems and conflicts over limited resources. One problem widely publicised by non-government organisations and environmental groups has been losses of mangrove forests (Naylor *et al.*, 2000). Mangroves are extremely productive coastal ecosystems and their decline has indeed been extensive—as much as 55–60% of the original forests have already been lost. However, most of that loss is due to clearing for rice production, grazing, urban development, fuel, construction materials, wood pulp and tourism; conversion to shrimp farms accounts for <10% (Boyd and Clay, 1998). In fact, the vast majority of new shrimp pond construction does not affect mangroves because these areas have proven to be not well suited for shrimp production due to acid soils and high construction costs. Mangrove buffer zones are now protected in many new shrimp farm developments, and replanting has become common.

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'Biological pollution' is a term that has been used to describe the potential effects of introduced aquaculture species on natural populations, primarily in the context of salmon (Naylor *et al.*, 2000). Atlantic salmon (*Salmo salar*) is the main salmon species reared artificially; aquaculture harvest of this fish in 1999 was ~800 000 tonnes or ~2.4% of total world aquaculture production (FAO, 2000). Gross (1998) recently reviewed and analysed the literature on the potential impacts of Atlantic salmon from aquaculture sites on wild populations and concluded that along with potential negative genetic and ecological effects, salmon aquaculture does offer some benefits for wild populations that are often overlooked. There has been a significant shift in consumer preference from wild salmon to farmed Atlantic salmon. Increased availability has decreased prices, resulting in less pressure on wild stock. Gross's conclusions were that aquaculture is not the root cause of the current poor state of wild salmon fisheries and conservation, but that mismanaged capture fisheries and habitat destruction have resulted in wide-scale extirpations, depletions and loss of biodiversity in both Atlantic and Pacific salmon. This occurred long before commercial salmon aquaculture appeared in the 1970s.

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Recent criticism has also centred on the use of fishmeal in aquaculture diets. Naylor *et al.* (2000) reported that aquaculture is 'a contributing factor to the collapse of fisheries stocks world-wide'. The authors further state that with aquaculture expansion, 'ever increasing amounts of small pelagic fish would be caught for use in aquaculture feeds to expand the total supply of commercially valuable fish'. In truth, fishmeal production has changed very little over the past 15 years (Figure 2). Adele Crispold (personal communication) from the FAO explains that market forces have simply reallocated the use of a fixed amount of fishmeal, but have not actually changed the total amount of pelagic fish harvested or fishmeal produced. The percentage of fishmeal used for aquaculture feeds has indeed increased from 10% in 1988 to 35% in 1998. But the large majority of fishmeal is still used in livestock feeds and for fertilisers—while the actual amount of fish harvested to produce fishmeal has remained relatively constant at ~30 million tonnes per year (FAO, 1999). An analysis of FAO data over the past 15 years indicates that there is no statistical relationship between aquaculture production, harvest rates for pelagic fishes or fishmeal production (Figure 2). A shift in fishmeal use toward aquaculture may actually represent an environmentally friendly use of this resource, as fish are more efficient feed converters than the primary users, terrestrial livestock.

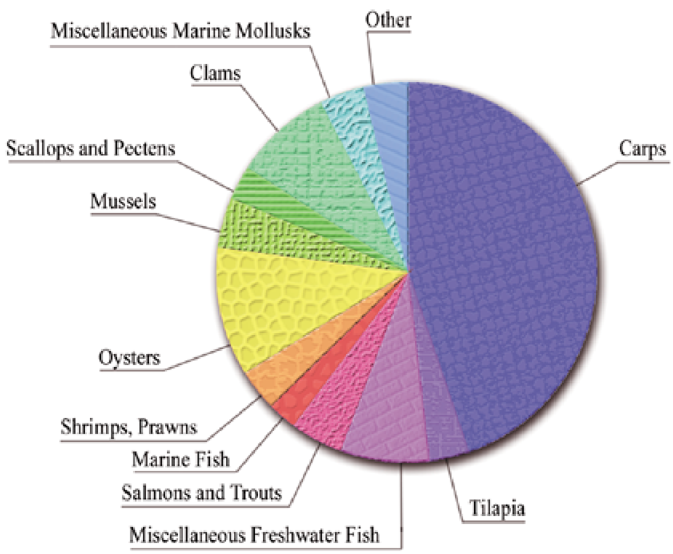

Fig. 3. The proportion of total aquaculture production accounted for by different taxonomic groups.

Naylor *et al.* (1998) also proposed that certain types of fish, particularly salmon and shrimp, are actually net consumers of fish, requiring as much as 3 kg of fish in their feed to produce 1 kg of farmed fish. Overall, these species represent a relatively small proportion of total aquaculture production (Figure 3). Furthermore, Forster (1999) points out that, based on classic values of energy flows, 10 kg of forage fish are required to produce 1 kg of a carnivore—such as salmon—in the wild. If by-catch values are taken into account, at least another 5 kg of fish can be added to the equation. Based on these considerations, even if farmed salmon or shrimp do utilise 3 kg of fish to produce 1 kg of weight gain, this would actually represent a significant ecological advantage compared to 10–15 kg of fish used or wasted in the growth and capture of 1 kg of wild salmon or shrimp. Also, when considered *in toto*, aquaculture is a huge net producer, generating 3.5–4.0 kg of food fish for each kg of pelagic fish used in fishmeal production.

Importantly, the efficiency of aquaculture production will improve further. As an industry, aquaculture is still in its relative infancy, thus knowledge of the nutritional requirements of most fish species is rather limited compared with poultry and other livestock. Naylor *et al.* (2000) noted that livestock feeds on average 'contain only 2–3% fishmeal'. However, 20 years ago, fishmeal was also the preferred source of protein for poultry feeds, just as is the case for some aquaculture species today. Reduced reliance on fishmeal came as a result of nutrition research, particularly the quantification of requirements for individual amino acids and energy needs as well as the rigorous evaluation of alternative ingredients. The search for alternative ingredients is already a research priority for aquaculture for exactly the same reason: the desire to minimise feed costs. In channel catfish diets, the proportion of fishmeal in the feed has decreased from 8–10% in 1990 to <3% currently, based on an improved knowledge of their nutritional requirements (Robinson and Li, 1996). Several other species can also be successfully fed with similarly low contents of fishmeal (Allan *et al.*, 1999). Other factors caused by the relative immaturity of the industry will also greatly benefit from continuing research. The introduction of vaccines, for instance, has reduced the amount of antibiotics used per kilogram of salmon cultured by over 97% (Klesius *et al.*, 2001).

In an earlier paper, Naylor *et al.* (1998) concluded that, due to a reliance on fishmeal, aquaculture of these species is being subsidised by the marine ecosystem. However, all human food production is eventually 'subsidised' by aquatic or terrestrial ecosystems. The production of some aquaculture species is indeed partially fuelled by primary and secondary productivity within the marine system, but fish caught in the oceans have been entirely subsidised by the marine ecosystem. Even the 'cultural species' identified by Naylor *et al.* (2000) as net producers, such as carp, tilapia and catfish, do not actually convert food to flesh with higher efficiency than other species such as salmon or shrimp. They are, in fact, only 'subsidised' by different ecosystems—the freshwater ecosystem in the form of natural food items or terrestrial ecosystems through the production of feed ingredients, such as corn or soybean, each of which has its own ecological costs. Prudent and proper use of fishmeal under certain situations may actually be advantageous for the environment. Due to its extremely high nutritional quality, i.e. the proper balance of amino acids and fatty acids, and extremely high digestibility, the use of some fishmeal in the diet can reduce waste production in the culture system compared with completely plant-based diets.

The demand for fishmeal could potentially be met by improved use of by-catch from wild capture fisheries (Howgate, 1995). The amount of by-catch killed and discarded annually is estimated to be between 18 and 40 million tonnes (FAO, 1999)—approximately the total amount of fish currently harvested for fishmeal production (30 million tonnes). There is also a significant amount of fish currently wasted due to the intentional discarding of part of the catch. This occurs when fishermen wish to save limited quotas at times when prices are low or when they practice 'high grading'—discarding smaller fish of low value to create capacity for species that achieve a higher price on the market (FAO, 1999). For some capture fisheries, as much as 40% of the total catch is discarded. In aquaculture there is much more control over production, harvest, processing and distribution (Howgate, 1995), and these practices seldom occur.

Capture fisheries and aquaculture should not be considered in isolation. In certain areas some supposedly 'wild harvest' fisheries are actually highly dependent on an aquaculture phase to produce young fish that are necessary to maintain current capture rates. In Alaska, for instance, aquaculture is basically 'outlawed'. However, without the aquaculture production of seedstock, Alaska's wild-harvest salmon and oyster industries could not supply a fraction of the total production currently generated. According to Coates (1996), the divisions between aquaculture and capture fisheries will rapidly fade and, in many regions, have already gone. In fact, the best hope of providing fish to meet future demands will likely be co-ordinated partnerships of aquaculture, managed wild fisheries, and wise protection and management of coastal zones and ecosystems.

Studies that do not weigh the relative costs and impacts of the different sources of fish are overly simplistic and not constructive. Skewed conclusions can cause negative public opinion that could impede environmentally responsible aquaculture and its ability to supply the projected 35 million tonnes of aquatic foods needed to meet the difference between demand and capture (FAO, 2000). Unfounded negative media coverage could further stifle aquaculture development in rural and low-income areas where its potential impact is greatest.

In a recent report, the FAO (2000) stated that 'irrespective of whether inaccurate information is generated deliberately to promote a specific cause, or inadvertently through ignorance, it can have a major impact on public opinion and policy making that may not be in the best interest of either the sustainable use of fisheries resources or the conservation of aquatic ecosystems'.

There are not too few fish—there are too many people. If agriculture had not developed to increase the production of terrestrial livestock, we would never have been able to support the current human population. A similar juncture has been reached or passed in fish supplies. Although per capita consumption has not increased substantially, population growth has increased to the point where capture fisheries alone can fill only two thirds of the current demand for fish, thus almost all future demand will have to be met by aquaculture. According to the FAO (2000), 'there do not seem to be any insurmountable obstacles to the continued growth of aquaculture'. Both aquaculture and capture fisheries cause environmental impacts, which can be substantially reduced through further research and improved management. However, if aquaculture is unfairly assigned a negative label through unbalanced ecological assessments, its potential contributions to present and future food securities could be severely compromised. This could be especially devastating in regions where high-quality protein is needed most. Moreover, it would increase the deficit between wild harvest rates and total demand for fish, which will actually further devastate stocks of many marine fish species. These consequences on both human and fish populations would seem to go against the stated intentions and missions of many of the groups currently attacking aquaculture.

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References

Allan, G.L., Williams, K.C., Smith, D.M., Barlow, C.G. and Rowland, S.J. (1999) Fishmeal replacements for shrimp and fish feeds in Australia. *Int. Aquafeed*, **4**, 10–16.

Alverson, D.L., Freeberg, M.H., Murawski, S.A. and Pope, J.G. (1994) FAO Fisheries Technical Paper No. 339. FAO, Rome, Italy.

Boyd, C.E. and Clay, J.W. (1998) Shrimp aquaculture and the environment. *Sci. Am.*, **58**, 59–65.

Coates, D. (1995) Inland Capture Fisheries and Enhancement: Status, Constraints and Prospects for Food Security. Paper presented at the Government of Japan/FAO International Conference on Sustainable Contribution of Fisheries to Food Security, Kyoto, Japan 4–9 December 1995.

FAO (1993) *Review of the State of Marine Fisheries Resources.* FAO Technical paper No. 335. FAO, Rome, Italy, 136 pp.

FAO (1997) *Review of the State of World Aquaculture*. FAO Fisheries Circular No. 886, Rev. 1. Rome, Italy.

FAO (1999) *The State of World Fisheries and Aquaculture 1998*. FAO, Rome, Italy.

FAO (2000) *The State of World Fisheries and Aquaculture 2000*. FAO, Rome, Italy.

Forster, J. (1999) Aquaculture chickens, salmon: a case study. *World Aquaculture Magazine*, **30**(3), 33, 35–38, 40, 69–70.

Garcia, S. and Newton, C. (1997) Current situation, trends and prospects in world capture fisheries. In Pikitch, E., Hubert, D. and Sissenwine (eds), *Global Trends in Fisheries Management*. American Fisheries Society Monograph Series, Bethesda, MD, 352 pp.

Gross, M.R. (1998) One species with two biologies: Atlantic Salmon (*Salmo salar*) in the wild and in aquaculture. *Can. J. Fisheries Aquatic Sci.*, **55**(Suppl. 1), 131–144.

Howgate, P. (1995) Contribution of Fish Processing to Food Security. Paper presented at the Government of Japan/FAO International Conference on Sustainable Contribution of Fisheries to Food Security, Kyoto, Japan 4–9 December 1995.

Klesius, P.H., Shoemaker, C.A., Evans, J.J. and Lim, C. (2001) Vaccines: prevention of diseases in aquatic animals. In Lim, C. and Webster, C.D. (eds), *Nutrition and Fish*

Health. Food Products Press. An Imprint of the Haworth Press, New York, NY, pp. 317–335.

Mace, P.M. (1997) Developing and sustaining world fisheries resources: the state of the science and management. In Hancock, D.A., Smith, D.C., Grant, A. and Beumer, J.P. (eds), *Second World Fisheries Congress*. CSIRO Publishing, Collingwood, Australia, pp. 98–102.

MacLennan, D.N. (1995) Technology in Capture Fisheries. Paper presented at the Government of Japan/FAO International Conference on Sustainable Contribution of Fisheries to Food Security, Kyoto, Japan 4–9 December 1995; and 1997. Review of the state of World Aquaculture. FAO Fisheries Circular No. 886, Rev. 1. Rome, Italy, December 1995.

Nance, J.M. and Scott-Denton, E. (1997) *By-catch in the Gulf of Mexico Shrimp Fishery*. In Hancock, D.A., Smith, D.C., Grant, A. and Beumer, J.P. (eds), *Second World Fisheries Congress*. CSIRO Publishing, Collingwood, Australia, pp. 1–20.

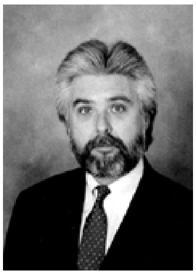
Naylor, R.L., Goldberg, R.J., Mooney, H., Beveridge, M.C., Clay, J., Folk, C., Kautsky, N., Lubchenco, J., Primavera, J. and Williams, M. (1998) Nature's subsidies to shrimp and salmon farming. *Nature*, **282**, 883–884.

Naylor, R.L., Goldberg, R.J., Primavera, J.H., Kautsky, N., Beveridge, M.C., Clay, J., Folk, C., Lubchenco, J., Mooney, H. and Troell, M. (2000) Effect of aquaculture on world fish supplies. *Nature*, **405**, 1017–1024.

Odum, E.P. (1979) *Fundamentals of Ecology*. W.B. Saunders, Philadelphia, PA.

Robinson, E.H. and Li, M.H. (1996) *A Practical Guide to Nutrition, Feeds, and Feeding of Channel Catfish*. Bulletin 1041, Mississippi Agricultural and Forestry Experiment Station, Mississippi State, Mississippi.

Speer, L. (1995) *Marine Fisheries, Population and Consumption: Science and Policy Issues*. WRI 1996. World Resources 1996–1997. WRI/UNEP/UNDP/World Bank. Oxford University Press, Oxford, UK, 365 pp.



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