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Clem Tisdell*

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BIOECONOMIC ANALYSIS OF AQUACULTURE'S IMPACT ON WILD STOCKS AND BIODIVERSITY

Abstract

Anderson theorizes that development of the aquaculture of a species of fish (also captured in an open-access fishery) favours the conservation of its wild stocks, if competitive market conditions prevail. However, this theory is shown to be subject to significant limitations. While this is less so within his model, it is particularly so in an extended one outlined here. The extended model allows for the possibility that aquaculture development can impact negatively on wild stocks thereby shifting the supply curve of the capture fishery, or raise the demand for the fish species subject both to aquaculture and capture. Such development can threaten wild stocks and their biodiversity. While aquaculture development could in principle have no impact on the biodiversity of wild stocks or even raise aquatic biodiversity overall, its impact in the long-term probably will be one of reducing aquatic diversity both in the wild and overall.

Keywords: Aquaculture development, aquatic conservation, biodiversity, common-property, fish farming, open-access fishery

BIOECONOMIC ANALYSIS OF AQUACULTURE'S IMPACT ON WILD STOCKS AND BIODIVERSITY

1. Introduction

Views differ about the likely impact of aquaculture (and of farming or husbandry generally) on the survival of species in the wild and about how such activity is likely to affect the stock of available genetic diversity. Some writers see farming (for example, of species threatened in the wild) as a positive force for conservation whereas others regard it as a serious threat to biological conservation. However, the situation is extremely complex. This article demonstrates that whether or not farming is a positive force for biological conservation (and adds to or subtracts from the available genetic stock), varies with circumstances, including the scale of farming activity.

Anderson (1985) argues that if markets are competitive, aquaculture is a positive force for conserving wild stocks of commercially exploited fish. His view is outlined and then shown to require important qualifications in the light of possible supply-side and demand-side interactions.

The type of analysis used by Anderson (1985) is a relatively short-term one and inadequate for considering long-term changes in the genetic stock. In the long-term, available genetic stock may be altered by human determined breeding of farmed species, and human selection of species, as well as natural events. Both the genetic stock of farmed species as well as that of wild stocks may exhibit regular long-term patterns of development due to 'lock-in' effects (Swanson, 1994) and due to the widening of markets, such as occurs with economic globalisation (Tisdell, 2002). Drawing on observations derived from genetic consequences of agriculture and the husbandry of terrestrial animals, possible long-term patterns of the impact of the development of aquaculture on the genetic stock in aquaculture and on the genetic stock of wild aquatic species are considered.

2. Anderson's Theory that in Competitive Conditions Aquaculture Favours Conservation of Wild Stocks of a Species

Anderson (1985, p.1) contends, on the basis of his theory, that market entry of competitive aquaculturists of a fish species subject previously only to capture "increases natural fish stocks, reduces price and increases total supply. If initially the natural fish stock is at a level below maximum sustainable yield, entry of the aquaculturalist[s] results in an increase in supply from the commercial fishery". However, this positive result for conservation of wild fish stocks is only true under favourable conditions. The results are not general ones. They rely on the assumption that the supply and demand for captured fish is independent of the supply of aquacultured fish and that aquacultured fish are perfect or close substitutes for captured fish of the same species. Furthermore, even given Anderson's (1985) assumptions, there is one circumstance in which economically viable aquaculture fails to increase natural fish stocks and to save a species that is both captured and aquacultured from extinction in the wild.

Let us consider the simplest illustration of Anderson's proposition using a modified form of his Figures 1. In this case, the capture fishery has a single equilibrium and it occurs at E_1 in Figure 1 implying that the stock of the fishery is below the level that yields maximum sustainable yield. The supply curve marked *SAS*N represents the supply curve of captured fish of a particular species and line *DD*N represents the market demand curve for these fish. The residual demand curve for aquacultured fish of the same species is marked *RGR*N. In the absence of aquaculture, the equilibrium at E_1 is stable and the price of the fish is P_3 per unit with supply being X_1^F. Now if aquaculture becomes profitable, total fish supplies can be expected to increase and the surplus from the capture industry may also rise as fish stocks increase with reduced harvesting pressure.

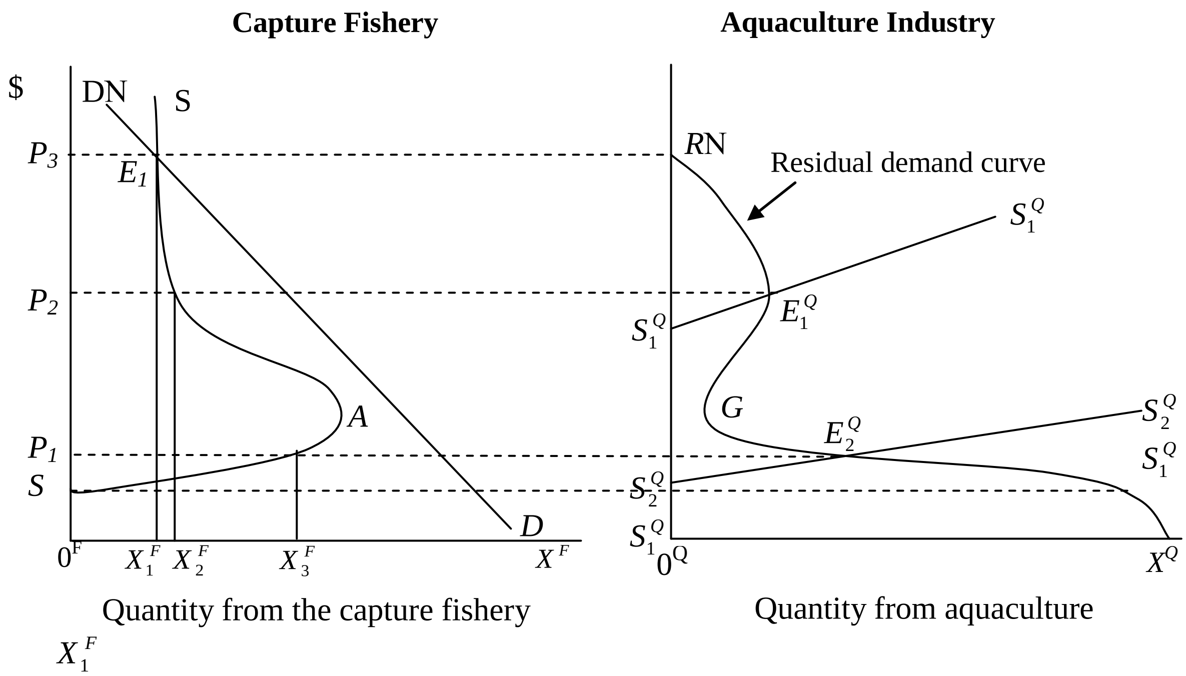

Figure 1 A case in which aquaculture is favourable to biological conservation of wild fish stocks

If, for example, in Figure 1, $S_1^Q S_1^Q$ represents the aquaculture supply curve, the aquaculture industry comes into equilibrium at E_1^Q. The price of the fish species concerned falls from P_3 to P_2 and the capture fisheries supplies rise from X_1^F to X_2^F. Total fish supplies are up. This is also true if the aquaculture supply curve is $S_2^Q S_2^Q$. But now supplies from the capture fishing are below maximum sustainable yield. In fact, if $S_2^Q S_2^Q$ is sufficiently low, supplies from the capture fishers may fall below X_1^F and in the extreme case, exploitation of wild stocks could become completely unprofitable. This, therefore, calls for qualification to Anderson's statement mentioned earlier that if initially the natural resource stock is overexploited, aquaculture results in increased supply from the commercial fishery.

Anderson (1985) also illustrates his theory for a triple equilibrium case for the capture fishery. But in none of the cases that he illustrates does he allow for the possibility that open-access capture fishing could lead to the extinction of wild stocks. In all the cases considered by him aquaculture increases the size of the wild stock.

However, even under the types of conditions envisaged by Anderson (1985), successful aquaculture may fail to save wild stocks from extinction. While it may save wild stocks from commercial extinction, it need not do so. This can be illustrated by Figure 2.

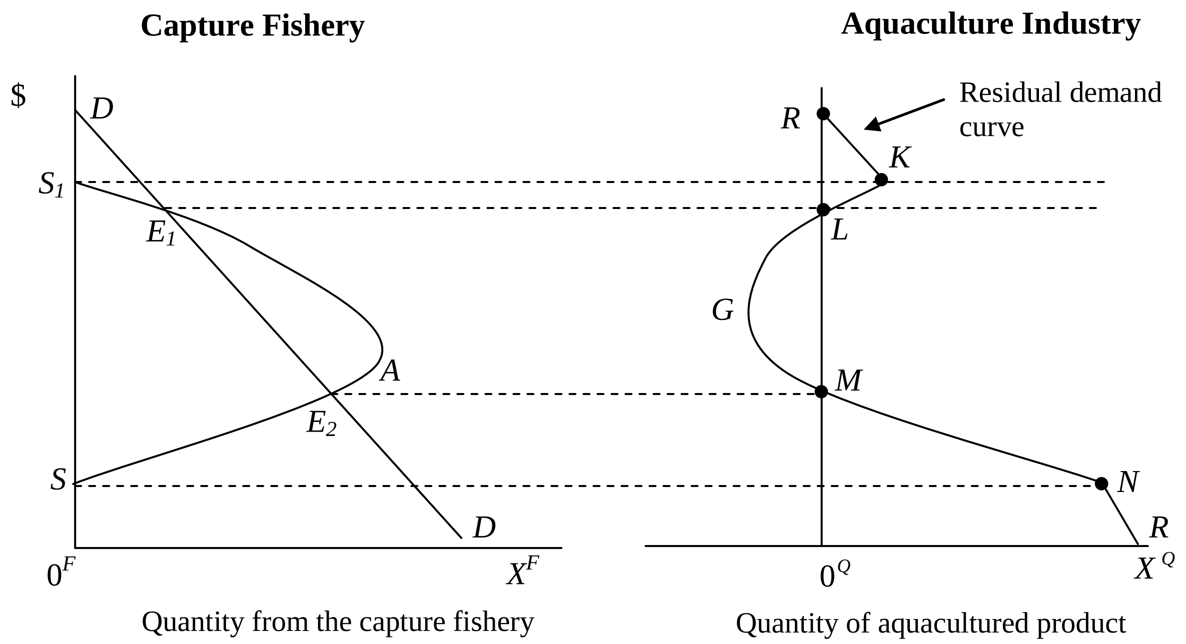

Figure 2 A case in which aquaculture may fail to prevent extinction of wild fish stocks

From Figure 2, it can be observed that if the supply curve from aquaculture cuts the residual demand curve (the demand for the aquacultured product between *R*N *and K*, aquaculture fails to prevent extinction of natural stocks given that E_1 is an unstable equilibrium. So even under the type of conditions envisaged by Anderson (1985), aquaculture may fail to have a positive effect in saving wild stocks from extinction. However, it is true that if the supply curve of aquaculture intersects the supply curve of aquaculture in the segment between *K* and *L*, its development will be a positive force for conserving wild stocks. This is given the implicit assumption that harvesting of wild stocks will cease at population levels that are so low as to result in elimination of these stocks. At stock levels above this where harvesting continues, survival of the wild population is assumed to occur. In further extension of the argument, this assumption could be varied.

Note that if the aquaculture supply curve does not intersect sections *LKR*N or *RNM* of the residual demand curve, the aquaculture industry is not competitive with the capture fishery and cannot survive if the equilibrium price of capture fish falls in the range *LM*.

Observe that given the assumptions involved in Figure 2, a species continues to survive only in aquaculture if the supply curve for aquaculture intersects the residual demand curve in its segment *R*N*K*.

In the long-term, the farmed species may show little or no resemblance to its wild ancestors. Many of the genetic characteristics of its wild ancestor may be eliminated by selective breeding. Thus the genetic pool will change, and genetic loss could occur even though the domestication of the species ensures its survival. But there could also be a possibility of some genetic gains (as well as losses) because human selection of farmed animals or species ensures the survival of genetic variants that may have failed to be selected in the wild. While it is probably true that human influenced selection on the whole reduces genetic diversity, it may not always do so even though its likely to alter the pool of genetic resources. The pool of today's domesticated or farmed livestock may show greater genetic variation than the pool of their distant ancestors, despite some genetic loss, even though the degree of this genetic variation has begun to decline in the last 200 years or so.

In any case, the genetic stock present in farmed animals is likely to become a different set to that of the original wild genetic stock. Therefore, if the species becomes extinct in the wild but is farmed, a part of its original genetic stock is liable to be lost. Thus, in Figure 3, if set A represents the original genetic stock of a species prior to its farming and if set B represents that after farming has occurred for some time, set B intersects with set A. If the wild species becomes extinct, genetic material represented by the set A~B is lost and only $A \cap B$ if the original genetic material is conserved. However, B~A represents new genetic material. Nevertheless, it should also be recognized that over a long period of time the genetic material in the natural stock might change so that rather than say set A of genetic material being present in the wild stock, another set C might apply after a period of time. Once again, set B might only partially overlap with this set. In this context, it might be noted that farming may result in irretrievable loss of some valuable genetic material present in the original wild stock or expected to evolve in that stock but it may also supplement the gene pool, although it need not. In other words, in some cases B could be a subset of A or of C.

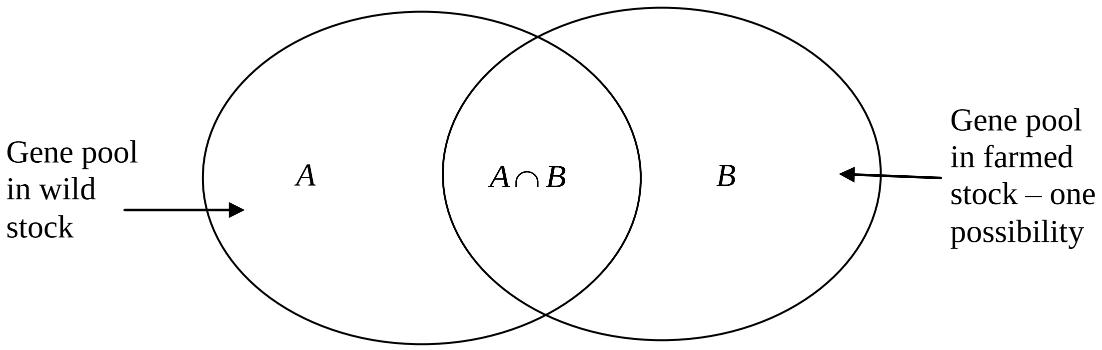

Figure 3 Gene pools of farmed stock and wild stock rarely coincide

Clearly this matter is quite complicated. It is especially so because under natural conditions, genetic stock is not stationary but changing and evolving. According to Lutz (2001, p.225):

"Around the globe, concern is growing over genetic conservation of wild populations of aquatic species – not only in terms of genetic variation within isolated populations, but also among populations of any given species. The later issue is more concerned with future evolutionary potential than current efforts to maintain species survival, but it has begun to play an important role in shaping conservation genetics policy for many aquatic species".

3. Need to Modify Anderson's Conclusion to Allow for Impacts of Aquaculture on Supply and Demand Functions for Captured Fish

Let us, however, return to Anderson's theory. Possibly the most serious limitation of Anderson's competitive model is failure to allow for possible impacts of aquaculture on supply and demand functions applicable to the capture fishery. Tisdell (1991, section 6.4) raises this issue in connection with farming generally. While the development of aquaculture need not always affect supply conditions in the capture fishery, in many cases such development shifts the supply curve of the capture fishery to the left. A leftward shift may come about because the aquaculture industry appropriates habitat used by wild stock;

competes with wild stocks for food resources, creates health or genetic risks for wild stock and relies on wild stock for seed/fingerlings, broodstock or "recruits" for aquaculture. While there might be some cases in which aquaculture has beneficial effects on the wild stock e.g. due to nutrient-enrichment of the environment as result of aquaculture, these cases are likely to be very rare indeed, if they occur at all.

Furthermore, there is also a possibility that aquaculture will raise the overall demand schedule for a fish species (cf. Asche et al., 2001). This could occur because aquaculture should permit greater regularity of market supply of a species subject both to capture and aquaculture and add to its market promotion. Nevertheless, there is also a small chance that aquaculture might on occasions reduce overall demand for a species e.g. if the aquacultured product is not identified and is subject to off-flavours (Tisdell, 2001). This problem is akin to the famous lemon versus plum problem (Akerlof, 1970).

Table 1 lists some factors that may cause the supply curve of a capture fishery to move left as a result of aquaculture development, and some that may cause the demand curve for a species that its both captured and aquacultured to move to the right.

Table 1
Some Circumstances in which Aquaculture has Negative Impacts on the Supply Curve of the Capture Fishery and Positive Impacts on Demand for the Fish Species Involved

Negative Impacts on Quantity of Wild Stocks
Aquaculture appropriates habitat used by wild stock for breeding, feeding, protection and so on.
Ranching involving collection of broodstock, seed or fingerlings or capture of more mature stock for aquaculture
Competition for shared food resources e.g. capture of prey of wild stock to feed aquacultured stock
Pollution or loss of resources used by wild stock because of spillover or environmental impacts of aquaculture
Disease and genetic risk to wild stocks from aquacultured stocks
Positive Impacts on Demand for Species as a Whole
Regular and widespread availability of product as a result of aquaculture may stimulate

demand for the fish species involved
Aquaculturalists may add to the market promotion of the fish species as a whole
The development of aquaculture may enable greater standardisation of the fish product. This is usually a plus as far as supermarkets are concerned (Young, 2001) and could have positive effects on demand both for the aquacultured and the captured product

If the development of aquaculture causes a leftward shift in the supply curve of the capture fishery or an upward shift in market demand for the species both captured and aquacultured, the development of aquaculture may have negative effects on wild stocks and Anderson's conclusions need not hold. For example, when aquaculture development shifts the supply curve for the capture fishery to the left, a lower price brought about by aquaculture suppliers may be associated with reduced supply of captured fish if the capture fishery is expending so much effort that it is operating at a level resulting in less than maximum yield, that is on the backward-bending portion of its demand curve. This case is illustrated in Figure 4.

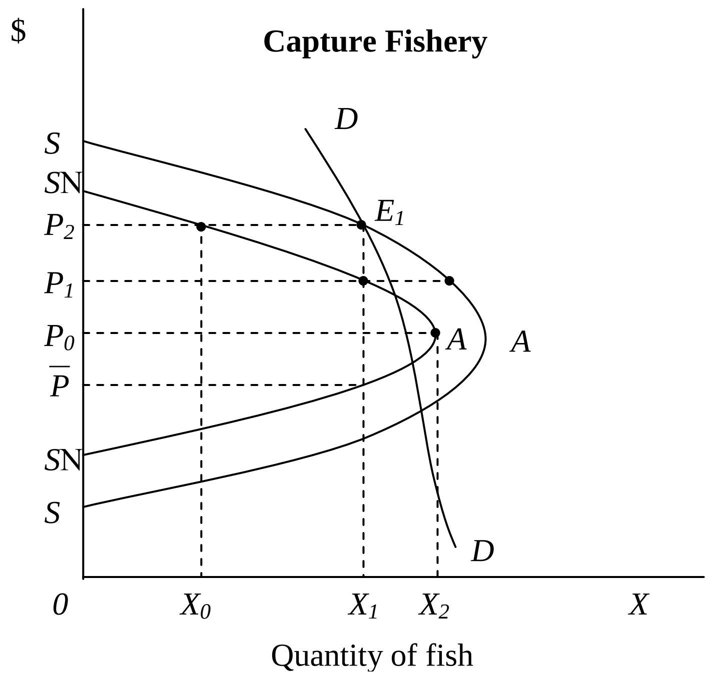

Figure 4 A case in which aquaculture has negative supply effects on the capture fishery

In Figure 4, only the position of the capture industry is shown. Curve SAS represents the supply curve of this industry and DD the demand for its fish before the development of a competing aquaculture industry. Once the aquaculture industry develops, then because of negative supply spillovers, the supply curve of the capture industry shifts leftwards to *S*N*AS*N. However, assume that the market demand curve for the species involved remains constant. Furthermore, suppose that initially the capture fishery is in equilibrium at E_1.

If aquaculture develops and causes the price of product cultured or captured to be in the range $P_1 < P < P_2$ supplies form the capture fishery fall. This contrasts with Anderson's case in which they rise in such circumstances. Supplies for the capture industry only increase in this case if $\overline{P} < P < P_1$.

Note that even if the capture fishery should attain maximum sustainable yield in the post-aquaculture situation, this yield and the maximum sustainable stock will be lower than in the absence of aquaculture. However, the impact of aquaculture on the yields of the capture fishery and its stock is liable to depend on the scale of aquaculture and the techniques used in aquaculture. Below some threshold of operation, for example, it is possible that aquaculture has little or no effect on the capture fishery. If on the other hand, aquaculture is on a considerable scale, it is liable to have negative supply consequences for the parallel capture fishery and can increase the likelihood of elimination of wild stocks. Because of the externalities involved, this may occur irrespective of whether replacement of wild stock by cultivated stock is the economically most efficient solution, and irrespective of whether aquaculture results in sustainable production and survival of the cultivated species in the long run.

The demand-side effects on the capture fishery from aquacultural development can be similar to the supply-side effects. An example is given in Figure 5. In this figure, the curve SAE_0S represents the supply curve for the capture industry. For simplicity, this supply curve is assumed to be independent of aquaculture development. DD is assumed to represent the demand for the fish concerned in the absence of aquaculture and D_1D_1 this demand after the development of aquaculture. Initially the industry is in equilibrium at E_0 with fish selling for P_0 per unit and X_0 being supplied by the capture fishery. But imagine that after aquaculture develops the price of the fish concerned rises to P_1. This price results in wild stock being fished to extinction in the case illustrated. In other cases, the price of fish after the development of aquaculture may be higher than P_0 but still intersect the supply curve for the capture fishery. In such cases, supplies from the capture fishery continue but are reduced compared to the pre-aquaculture situation. Once again this is a consequence not predicted by Anderson's (1985) model.

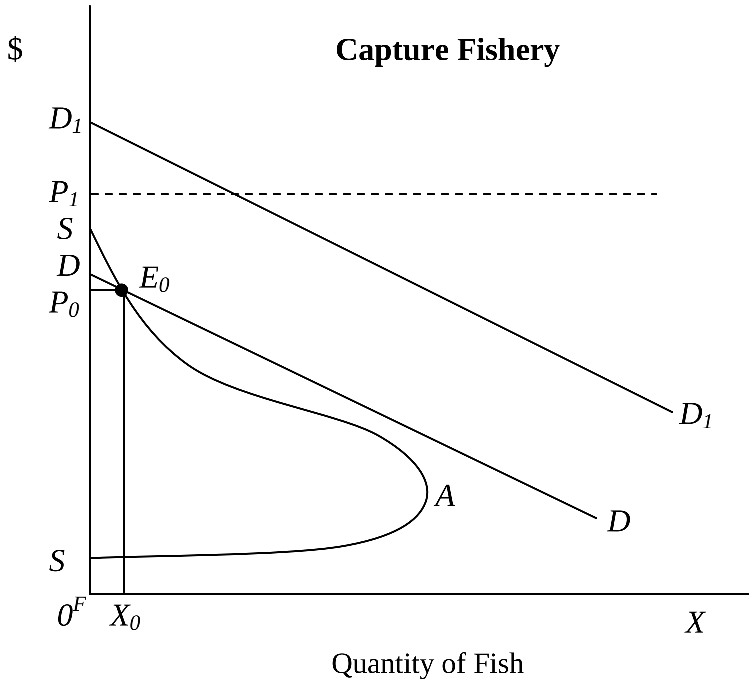

Figure 5 Demand-side effects from the development of aquaculture are liable to put pressure on wild fish stocks and in some cases may result in their elimination and results different to those predicted by Anderson's (1985) model.

Thus, it is clear that both demand-side and a supply-side spillovers from the development of aquaculture can have negative impacts on the biological conservation of wild stocks, even though in some circumstances neutral or positive consequences are possible. While the above modelling, assumes, as does Anderson (1985), that captured and cultured fish of the same species are perfect substitutes, this assumption can be relaxed. It is even possible for these products to be complements to some extent and for the type of conservation consequences outlined above to occur.

4. Aquaculture and Long-Term Patterns of Change in the Stock of Aquatic Genetic Diversity

The timing and pattern of development of aquaculture has implications for its effects on biodiversity. Meryl Williams (1997, p.19) observes:

"Despite great technical advances, modern aquaculture is still a new technology and requires further progress to meet the supply challenges ahead. Enhanced development of aquaculture is only recent. Even though the aquaculture of carp began at least 2500 years ago in China, carps were only successfully bred in hatcheries as recently as the early 1960s. Most current aquaculture is still quite rudimentary, relying on natural supplies of seed stock, unimproved wild types of fish, and simple culture technologies and inputs. Feeds are also largely unimproved, and the nutritional requirements of most species are not known at all except in general terms from studies of diet and feeding preference."

Therefore, aquaculture has not developed globally as widely and as intensively as agriculture. It is still much involved in the process of selection of species for culture and developing different strains of cultured species. This is occurring at a time when the world is already highly globalised and humans have intensive techniques that tend to isolate husbanded species from their surrounding natural environment. By contrast, livestock husbandry developed widely at a time when livestock were more dependent on their surrounding natural environment than now and when there was much less globalisation, economic and otherwise. The early circumstances involved in animal husbandry resulted in the development of diverse breeds globally. It seems probable that the extent of diversity of domesticated livestock increased until a few centuries ago. It has, however, declined in the last two centuries or thereabouts for reasons outlined in Tisdell (2002). These reasons include market extension (as reflected, for example, in economic globalisation) and scientific advances that have enabled animal husbandry to be undertaken most profitably in relatively uniform artificial environments. Wild ancestors of many domestic livestock have disappeared in this development process due to factors such as the conversion of their habitat to agricultural use and due to hunting. For example, the Auroch *Bos primigenius*, the ancestor of cattle, disappeared in the 1600s (Alderson, 1994, p.11).

Given its later development, it is possible that aquaculture will not develop genetic diversity to the extent that it existed in domestic livestock. Nevertheless, it is likely that the number of species and variation of species aquacultured will continue to increase for some time to come. This may occur for several reasons. (1) Aquatic farming environments on the whole and not as closely regulated and uniform as those for livestock and a greater range of environments for aquaculture may exist globally. To take full advantage of the diversity of these aquatic environments, further human selection of breeds and species and development of strains is needed. (2) Much learning is still occurring and search is required to discover new species and varieties suited to aquaculture and techniques for aquaculture are still being developed. Aquaculture is probably still on the lower branch of the learning curve. In the earlier stages of learning about production possibilities, the number of techniques and products tried in a developing industry tends to rise and then decline as 'superior' techniques and products are identified. One might expect a similar pattern to emerge in the development and selection of species and varieties of species for aquaculture. Eventually, however, aquaculture husbandry might become more standardised and greater control might be achieved over environments for such husbandry. As with livestock, this growing uniformity is likely to result in fewer species or varieties of aquacultured species in the very long run.

Hence, the time-path of evolution of the diversity of genetic stock used in aquaculture might accord with the pattern illustrated by curve *ABC* in Figure 6. Furthermore, as aquaculture first develops, it may have little impact on the diversity of wild aquatic genetic stock, but subsequently may cause this to decline at a rapid rate before its further negative effect on the stock is moderated, as is indicated by curve *DEF*. We are probably still far from reaching the peak of curve *ABC* because as yet only a small proportion of food fish are used in aquaculture (cf. Williams, 1999, p.20).

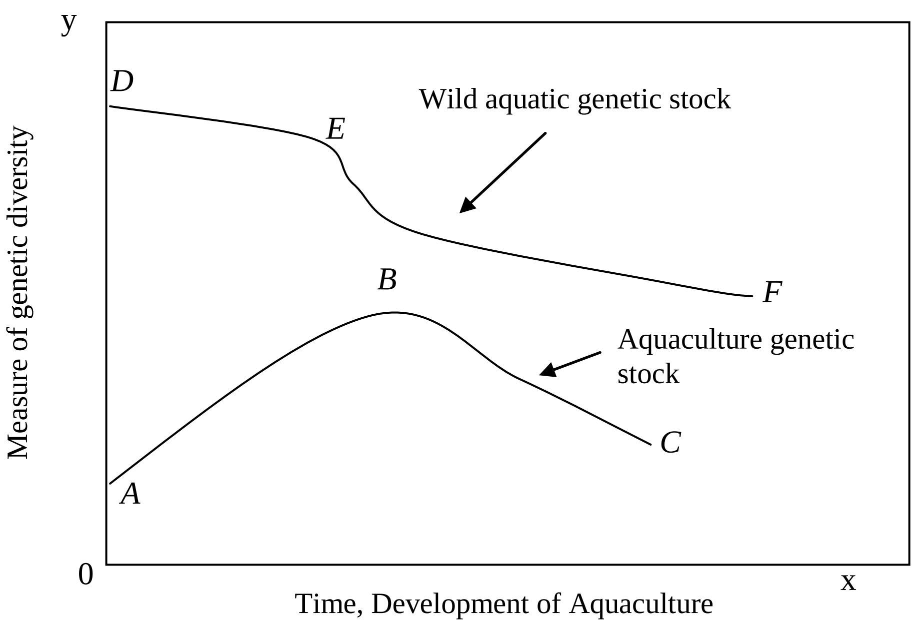

Figure 6 Possible relationships of biodiversity to the development of aquaculture. Relationships are not to the same scale.

5. Concluding Comments

While the development of aquaculture can have favourable impacts on the survival of wild fish species and stocks of captured fish, the competitive market model of Anderson (1985) suggests more favourable effects than in fact are likely. Even given Anderson's (1985) model, the development of aquaculture may fail to save a captured fish species from extinction. However, the likelihood of the development of aquaculture having a negative consequences for conservation of a species also exploited by the capture fishery increase when the aquaculture industry has negative impacts on the supply of the capture fisheries or raises the demand for the fish species subject to both aquaculture and capture.

Given our experience with the long-term genetic consequences of agriculture, it seems highly likely that as aquaculture develops and expands, this will tend to reduce wild genetic stock. In addition, although genetic diversity within aquaculture may initially rise, in the very long-term, it might be expected to decline after peaking. However, the later development of aquaculture compared to agriculture, especially compared to livestock husbandry, may result in some differences in the evolving extent of animal diversity in aquaculture. The institutional arrangements affecting aquaculture's development today, particularly globalisation factors, are quite different to those surrounding the earlier development of livestock husbandry. So some differences in patterns of global genetic development in aquaculture and in livestock production might be anticipated.

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