CHAPTER 13

INDIGENOUS SPECIES FOR AFRICAN AQUACULTURE DEVELOPMENT

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Abstract: From the history of introductions and the development of successful aquaculture elsewhere, it appears that the use of exotic species to speed up the rate of aquaculture development in Africa is unlikely to be an efficacious strategy. The major sustained aquaculture industries worldwide evolved from close working relationships between pioneering investors and local research-and-development institutions. The use of indigenous species avoids many environmental risks, facilitates broodstock and hatchery management at the farm level, and can increase the effectiveness of selective breeding programs. Public-sector involvement in the domestication and marketing of indigenous species can strengthen research, development, and education; broaden the range of investors; create more jobs; and increase the social benefits accruing as a result of aquaculture development.

Key words: Africa, alien species, aquaculture, Cameroon, ecosystem, environment, ecological impacts, indigenous species, introduction, Malawi

1. INTRODUCTION

Aquaculture has made steady progress over the past 40 years, but environmental constraints are now being imposed either by natural ecosystems or man-made regulation. While many negative environmental impacts can be ameliorated through improvements in fish feeds, facility design, and waste processing technology (Boyd, 1995; Mires, 1995a), the impact of escapees from aquaculture on indigenous biodiversity is, in almost all cases, unavoidable (Shelton and Smitherman, 1984; Beveridge and Phillips, 1993).

In this article, I examine the context and history of aquaculture-related introductions of exotic freshwater finfishes into Africa and propose that an

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emphasis on the domestication of indigenous species can decrease environmental consequences of escapement while simultaneously stabilizing and diversifying the industry and ensuring the equitable distribution of benefits. Although many of the comments made here may be broadly applicable, the author's experience is predominantly in African systems and it is these to which the following arguments specifically apply.

2. HISTORY OF AQUACULTURE INTRODUCTIONS IN AFRICA

Increasing poverty and human population sizes in developing countries increases the pressure on governments to maximize food production as rapidly and as cheaply as possible. Urgency often results in a failure to carefully review costs and benefits. Policy-makers trying to feed hungry people and investors seeking quick returns are strongly compelled by the perceived magic bullet of importing for aquaculture an alien species that has proven its worth in aquaculture in other countries or regions (New, 1999).

The track record of aquaculture-related introductions (Table 1) shows that bringing in exotic species to get quick results seldom produces the desired outcome (Satia, 1991). In reviewing 212[1] international[2] introductions of freshwater fishes into Africa for aquaculture, only 33 (16%) were found to have resulted in the establishment of an industry with output of more than 10 metric tons (t) per year in 1997 (FishBase, 1998; FAO, 1999). Of these, 10 (30%) were of common carp (*Cyprinus carpio*) from Asia and Europe and 7 (21%) were of Nile tilapia (*Oreochromis niloticus*) from other African countries. The balance was of mixed cyprinids and rainbow trout (*Oncorhynchus mykiss*). Typical is the case of Zambia, where 39 introductions resulted in sustained aquaculture of only Nile tilapia and common carp (Thys van den Audenaerde, 1994; FAO, 1999). Production of these two species in 1997 was only 133 and 275 t, respectively, compared to 2680 and 1010 t for the indigenous *Oreochromis andersonii* and *Tilapia rendalli*, respectively (Table 2).

In terms of weight produced, over 99% of the total production of exotic species in Africa was of common carp in only two countries: Egypt (22,000 t) and Madagascar (6,000 t).[3] Currently, the common carp industry in Egypt is in serious decline due to the reduction of government subsidies and consumer preference for the indigenous Nile tilapia. In total, exotic species account for only 15% of African aquaculture output (Garibaldi, 1996; Bartley and Casal, 1998). In Asia, the powerhouse of world aquaculture, 517 introductions of primary and secondary freshwater species have resulted in a total contribution of only 5% to total output (Garibaldi, 1996).

[1] FAO (1999) reports a total of 470 freshwater and marine introductions to Africa.

[2] Most available datasets do not permit the comparison of production statistics with species translocation within a country.

[3] Recently, two projects in Zimbabwe have started operating at a combined output of 6,000 t per annum of Nile tilapia (Cecil Machena, Africa Resources Trust, personal communication, November 1999).

Table 1. Effects of some characteristic aquaculture-related introductions. Of 212 introductions of freshwater species, 33 have generated sustained aquaculture of over 10 metric tons (t) per annum; only 14 produce more than 100 t

Aquaculture introduction	Environmental impact	Tons cultured	Reference
Oreochromis niloticus to Kenya	Displaced endemic *O. esculentus* in Lake Victoria	124	Lowe-McConnell, 1988
Tilapia zillii to Uganda	Displaced *O. variabilis* in Lake Victoria	20	Fryer and Iles, 1972; Lowe-McConnell, 1988
Osphronemus goramy to Mauritius	Naturalized, minimal	0	Moreau et al., 1988
Oreochromis macrochir and *Tilapia rendalli* to Cameroun	Naturalized, unknown	0	Nguenga, 1988
Cyprinus carpio to Kenya	Displaced local species	<0.5	Lever, 1996
C. carpio to Zambia	Not established	275	Woynarovich, 1997
C. carpio to Malawi	Not established	<10	Msiska, 1993
C. carpio to Zimbabwe	Naturalized	0	Lever, 1996; Binali, 1997
O. niloticus to Zimbabwe	Introgression and reduced catches of indigenous tilapias	133	Lever, 1996; Binali, 1997
Clarias gariepinus to Cameroun	Naturalized	<0.5	Lever, 1996; FAO, 1999
Carassius auratus to Madagascar	May have introduced parasites	0	de Moor and Bruton, 1988; Moreau et al., 1988
Chinese carps to Ethiopia	Reportedly naturalized	2	Moreau et al., 1988; Lever, 1996
Ctenopharyngodon idella to the Republic of South Africa	Introduced fish tapeworm	<0.5	de Moor and Bruton, 1988
C. carpio to Madagascar	Naturalized	6,105	Moreau et al., 1988; FAO, 1999
C. carpio to the Republic of South Africa	Reduced catches of local species, introduced 7 exotic parasites	35	de Moor and Bruton, 1988
Heterotis niloticus to Côte d'Ivoire, Cameroun, Central African Republic, Gambia, Congo	Naturalized	2	Lever, 1996; FAO, 1999
Oncorhynchus mykiss to Morocco	Unknown	100	FAO, 1999
Salmo trutta to the Republic of South Africa	Eradicated local species	0	de Moor and Bruton, 1988
O. niloticus to Madagascar	Genetic introgression, replaced local species	0.5	Moreau et al., 1988; Lever, 1996

One reason why exotics have failed to produce rapid growth of the aquaculture sector in Africa is because the germplasm being cultivated is only one (but not currently the most important) constraint to development. African fish

Table 2. Production of indigenous species in selected African countries, as reported to FAO (1999). Of 49 industries that produce over 10 metric tons (t) per annum, only those with outputs of ≥100 t are listed. Data for Malawi were extrapolated from ICLARM-GTZ (1990) and Fisheries Department internal reports

Country	Species or species group	1997 production (t)
Côte d'Ivoire	Siluroids	192
Egypt	Clariids	2,301
	Mugil cephalus	1,931
	Oreochromis niloticus	30,416
Ghana	*Clarias gariepinus*	100
	Oreochromis niloticus	300
Kenya	*Oreochromis niloticus*	124
Malawi	Mixed tilapias	>300
Nigeria	Characoids	3,480
	Clariids	5,357
	Heterotis niloticus	2,956
	Oreochromis niloticus	1,589
	Synodontids	550
Sudan	*Oreochromis niloticus*	1,000
Tanzania	*Oreochromis niloticus*	250
Tunisia	*Mugil cephalus*	485
Zambia	*Oreochromis andersonii*	2,680
	Oreochromis macrochir	407
	Tilapia rendalli	1,010

possess adequate aquatic biodiversity to sustain aquaculture development. Asia relies on indigenous species for 95% of total production, and the number of indigenous freshwater fish species in Asia and Africa is approximately the same: 2943 and 2660, respectively (Fishbase, 1998; Christine Casal, WorldFish Center, personal communication, November 1999). However, far more important than the lack of species are inadequate inputs (van der Mheen and Haight, 1997; Williams, 1997); shortage of seed (Ruddle, 1993; Coche et al., 1994); lack of the necessary research, development, and extension (R, D, & E) to backstop industrial growth (Lazard et al., 1991; ALCOM, 1994); and poor market development (Hecht, 1997). While inadequate inputs affect indigenous and exotic species alike, indigenous species may have an advantage in seed production, R, D & E, and markets.

Well over 90% of the African fish-farming sector is composed of smallholders (King, 1993). To be viable and self-sustaining, the smallholder sector needs species that can be reproduced without complicated and/or expensive interventions. Encouraging dependence upon exotic species that require hatchery facilities for propagation will only exacerbate the fingerling supply problem (Satia, 1991). Eknath (1991) identified inadequate hatchery reserves of broodfish as a major cause of inbreeding depression in cultured stocks. For indigenous species, ready reserves of broodstock are already adapted to local environmental and climatic conditions for their reproduction (Lowe-McConnell, 1988).

New feeds, disease therapies, reproduction techniques, and sometimes even pond designs are needed when species additions or changes are taking place (Beardmore et al., 1997). The R&D process, through which new management strategies are developed, is probably the best way to produce both the needed technology and the skilled scientists and extension personnel to support aquaculture development (Gaillard, 1990; Lazard, 1992; Van Crowder and Anderson, 1997). Because of cost and/or environmental concerns, exotic species are normally introduced to only one research facility at a time. In situations where high-quality human resources are in short supply, this may limit the number of researchers who study the domestication of a particular species to only one or two. With indigenous species, any student, scientist, would-be farmer, or extension agent in the country can get involved. This not only increases the number of minds focused on the problem, but enhances the opportunities for collaboration and synergism.

Many technology-driven development initiatives introduce complete production systems (including the culture species) more or less without regard to markets (Ruddle, 1993; Christensen, 1994). The common carp industry in Egypt is a good example. Carp were introduced as an ideal fish for culture in rice paddies. Millions of carp fingerlings were produced in government hatcheries and delivered at subsidized prices to rice farmers. At give-away prices, these fish were a source of cheap protein to the urban poor, but as government subsidies declined and the price of carp rose to cover costs, consumers with sufficient income switched back to consumption of the indigenous tilapias while poorer segments of the market simply did not buy fish. Such an outcome was anticipated by Street and Sullivan (1985). Carp production in Egyptian rice fields collapsed from a reported 21,000 t in 1996, to less than 7,000 t in 1997 (FAO, 1999).

For whatever reasons, the track record shows that indigenous species are more likely to contribute to local economic growth and put food into local markets faster than exotics. They are also much less likely to damage the environment when they escape from aquaculture facilities.

3. ENVIRONMENTAL CONSEQUENCES OF ESCAPEMENT

For aquaculture, the most commonly introduced groups have been the carps and tilapias. The opportunistic habits that have made these fishes good aquaculture candidates also render them highly competitive for resources and potentially disruptive of the environment (Barlow and Tzotzos, 1995; Bartley and Casal, 1998). The planktivorous Chinese carps, for example, have the capability to distort food webs by targeting primary producers and consumers in their feeding activities (Leventer, 1981; Costa-Pierce, 1992). The aggressive and territorial tilapias alter food webs (de Moor and Bruton, 1988; Bruton, 1990) and reproduce so effectively that they can rapidly displace indigenous species (Moreau, 1983; Lowe-McConnell, 1988). The widely dispersed common carp muddies water, thus destroying aquatic vegetation and phytoplankton that form the basis of most aquatic food webs (Moreau et al., 1988). The introduction of carps in particular has been implicated in the spread of exotic diseases and parasites to indigenous species (de Moor and Bruton, 1988; Paperna, 1996).

The threat to indigenous ecosystems from exotic fish introductions is considerable (de Moor and Bruton, 1988; Courtenay and Stauffer, 1990). Many cases exist where the importation of species has resulted in the destruction of indigenous fish populations or habitats (McNeely et al., 1995; Moreau, 1997). The importation of the common carp to North America and the stocking of Lake Victoria with the Nile perch are only two examples of the disastrous effects that might be expected from introduction of exotics.

Many of the worst impacts from introductions have occurred in disrupted environments (Moreau et al., 1988; Courtenay and Stauffer, 1990; McNeely et al., 1995). While it is difficult to separate causes in such situations, much current ecological theory (Barlow and Tzotzos, 1995; McNeely et al., 1995) supports the hypothesis that introduced species may not have much impact until a stressed environment opens a sufficiently broad niche into which ‘‘weedy’’ species, such as those often used in aquaculture (Beveridge and Phillips, 1993), might expand (Courtenay and Stauffer, 1990). The history of the common carp in the Columbia River (northwestern USA) is a case in point. Introduced in the 1800s, the carp had no significant adverse environmental impact until extensive dam construction in the 1940s and 1950s slowed currents and warmed the water to the point where it had a competitive advantage over the indigenous cold-water species. Common carp have since contributed substantially to decreased water quality, loss of aquatic vegetation, and consequent declines in indigenous species—the salmonids in particular (Lever, 1996).

4. IMPROVED GERMPLASM FOR AQUACULTURE

That improvements in germplasm can increase production is almost unarguable. However, how these improvements are made can have a large impact on the rate of progress and on who benefits, and how. There are two general approaches to improving germplasm for aquaculture:

1. import an exotic species or improved variety developed elsewhere (centralized approach);
2. locally develop a new species or variety (decentralized approach).

In the past, the option of domesticating or breeding a new variety in a central location and then subsequently disseminating seed or broodstock has been favored by the international R&D establishment. This approach requires the international and often intercontinental transfer of genetic material and involves questions of genotype $\times$ environment (G $\times$ E) interactions, which render improved genotypes less competitive in culture systems that differ from those under which they were bred.

A major advantage of the centralized approach is that complicated technologies can be more easily handled and controlled in larger, more sophisticated labs. Breeding progress is faster. For example, the genetically improved farmed tilapia (GIFT) strain of *Oreochromis niloticus*, developed by ICLARM, the Asian Development Bank, and the United Nations Development Program in the Philippines, grows 20–70% faster than most domesticated *O. niloticus* strains. However, in Thailand and China, the GIFT fish exhibits signs of $G \times E$ interaction and is not substantially superior to locally adapted and bred strains. The GIFT fish, though, was produced in 4 years while the strains in Thailand and China have been domesticated for 30 and 20 years, respectively (ICLARM, 1998).

Well-documented examples of successful introductions of exotics for aquaculture are not plentiful. In most places, systematic comparison of local and exotic species was not conducted, either before or after the introduction (Pillay, 1992). Nevertheless, if $G \times E$ interactions and possible environmental impacts are negligible, one could argue that this approach provides more food to more people faster than the longer process of developing local species or strains.

In addition to growth rate of individual fish, however, governments contemplating introduction of exotic germplasm must consider the equitable accrual of benefits and distribution of environmental risks. In Africa, fingerling production is not generally based on centralized hatchery systems, and this situation is not changing. African governments that have tried in the past to produce low-cost fingerlings for support to low-income farmers are now increasingly unable to manage their hatchery programs and are, in fact, divesting themselves of this responsibility (Coche et al., 1994; Vincke, 1995). The private sector is unlikely to take up hatchery technology unless it has a market that can pay for the product.

In this situation, larger, vertically integrated farms are the most likely beneficiaries in the short term (over which time frame the centrally bred varieties have the advantage of being more quickly developable). This is what has happened in the USA catfish and Norwegian salmon industries (Forster, 1999). In Africa, where the vast majority of consumers are also producers, people cannot afford to pay for fish grown on large commercial farms and so most of the produce is sold to luxury markets or exported (Satia, 1991; Corbin and Young, 1997).

Figure 1 presents a model for how total aquaculture output might be enhanced while keeping more investors and laborers in the industry. As production and the number of farmers increases, market limits or increases in efficiency favor some producers who come to dominate the market for a particular species. Without alternative markets, less competitive producers begin to fall out, with associated loss of employment and waste of developed infrastructure. Equilibrium 1 is the level of investment supported by a highly

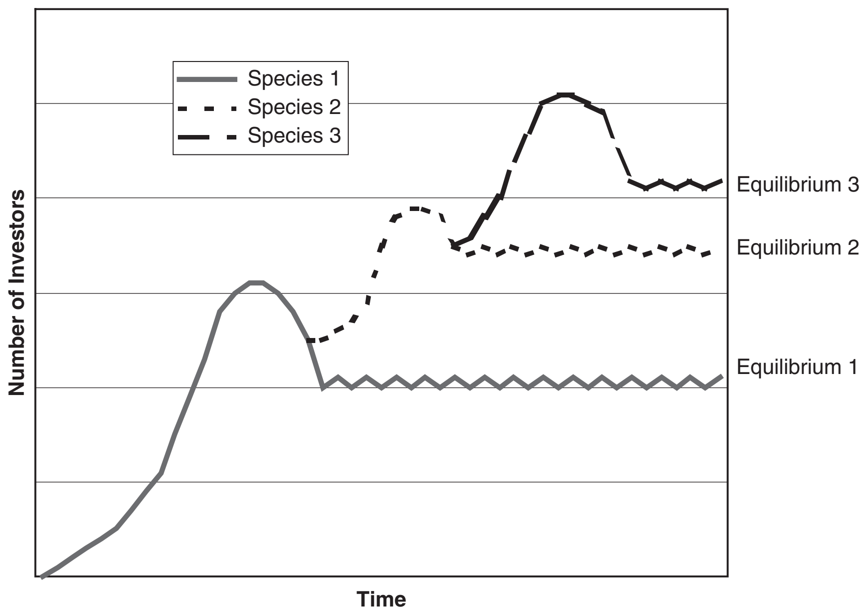

Figure 1. A theoretical model of how domestication of new species can enhance employment and investment in aquaculture. Equilibrium 1 is the point where the initial aquaculture industry stabilizes with the culture of one main species. Equilibrium 2, based on the domestication of a second species, has taken advantage of existing infrastructure to add quickly but marginally to investment levels. At Equilibrium 3, even less of an increment has been added, but opportunities for employment and investment have been further increased

efficient, single-species industry. With alternative species and markets, additional investment and employment can be supported (Equilibria 2 and 3), although overlap among producers will probably mean lower overall investment levels for each new species added. On the other hand, lead-time to full market exploitation should become shorter as more experienced farmers lead the transition to each successive new species. Since the markets for many species overlap (Brummett, 2000), this model would produce the greatest impact if new species brought in actually increase the overall size of the market or access new markets. In Israel, for example, polyculture of cyprinids and tilapias served largely to increase yield, but did not develop new markets. Only when striped bass and salmonids were introduced did new buyers start to eat fish. There is a clear role for market analysis prior to making major investments in the development of new species.

Almost any kind of economic growth in Africa is welcome, but evidence exists that directing assistance to rural poverty alleviation is more efficient than just making rich people richer and hoping for trickle-down effects (Delgado et al., 1998; Winkleman, 1998).

Local improvement of an already-domesticated species normally takes longer than the centralized approach. The decentralized approach requires more people that become involved and is consequently less efficient in terms of capital use. It also tends to be more difficult to implement within the short-term projects preferred by the donor community. However, as described above for more general R&D directed toward improved aquaculture technology, the benefits of developing local capacity to do biological assessments and hatchery management at the same time as the germplasm is being enhanced might outweigh the increased cost.

In terms of beneficiaries, the decentralized approach can include local economic and management constraints in the species selection and modification process, thus making new germplasm available to a broader range of local users. In terms of risk, local dissemination of indigenous species would seldom require more than the movement of genetic material from watershed to watershed (which may or may not involve national borders). In addition, $G \times E$ interactions in these ‘‘horses for courses’’ approaches are expected to be minimal.

Successful applications of the decentralized approach are widespread. In Malawi, common carp were considered for introduction and rejected when their performance was tested and judged inferior to local species (Msiska and Costa-Pierce, 1993). Instead, programs to domesticate and improve local tilapias (Brooks and Maluwa, 1997) and *Barbus* species (Brummett and Katambalika, 1996) were successfully undertaken. In Côte d’Ivoire, the domestication of *Heterobranchus longifilis* doubled growth rates over the previously cultured *Clarias gariepinus* (Breine et al., 1995); *H. longifilis* now contributes substantially to local aquaculture (Otémé, 1994). Ongoing research within the International Network for Genetics in Aquaculture (INGA) is aimed directly at this approach for the development and dissemination of improved indigenous germplasm in Africa and Asia.

5. A DIVERSE AND STABLE INDUSTRY

Within specific agroecological zones, the aquaculture industry has tended to specialize. States on cold oceans with sufficiently protected areas along their shores produce Atlantic salmon (*Salmo salar*). Tropical countries with suitable coastal areas produce shrimp (*Penaeus* spp. and related species). Throughout the Mississippi delta in the USA, farmers with bottomland grow channel catfish (*Ictalurus punctatus*). Concomitant with specialization has been a convergence of technology so that systems vary little from place to place. This has been fostered by the close working relationship normally established between pioneering entrepreneurs and R&D institutions supported by public funds. Once technology is standardized and shown to be profitable, investors pour in.

Since all investors are competing in very similar (if not the same) markets, economic viability comes to rely increasingly on smaller and smaller profit margins. Such cycles have resulted in large numbers of dropouts as ventures with comparative advantages for a particular species increase production and push prices below the break-even point for others. While some go out of business due to production inefficiency, many others are simply victims of circumstance. Increased efficiency and reduced numbers of farms means fewer jobs. Some bankrupt installations are sold to competitors, but others are simply abandoned for lack of a buyer in a saturated market. The Norwegian Atlantic salmon and the USA channel catfish industries have followed this general pattern, as indeed have many other agrobusinesses (Forster, 1999).

An example for the Israeli common carp industry is shown in Table 3. Until 1965, virtually all of Israel's aquaculture production was of common carp. From 1955 to 1965, efficiency increases lead to improvements in average yield, which precipitated (from 1965 to 1987) a decline in total area under water of 2325 hectares (almost 50%) and a decline in the number of farming businesses from 88 to 58. During this entire consolidation period, overall production steadily increased from 8680 to 13,979 t per year.

Over recent years, the enthusiasm for private-sector-driven economic expansion has led to a reduction in the financial resources available to public-sector research. The reduction in government hatcheries in Africa is only one symptom of this trend. In the USA, more and more aquaculture research is paid for by species-specific commercial aquaculture firms or associations. This research aims to only slightly improve profit margins and reduce environmental impacts (New, 1999) and is very seldom aimed at giving competitors options in the market.

While the loss of productive infrastructure and jobs may be affordable in Norway or the USA, it is much less so for developing countries. Under these conditions, it makes sense for public research expenditures to be directed at diversification of the aquaculture industry so as to open niches for a wide range of producers.

One way to do this is to establish long-term R, D, & E programs aimed at constantly domesticating new species and developing markets for them. The development of the Atlantic salmon and channel catfish industries illustrate how a close working relationship between researchers and farmers can lead to the elucidation of efficient aquaculture technology. Marketing, however, is often overlooked. An excellent case in point was the rapid growth and collapse of the South African clariid catfish industry. Scientists and farmers working together fostered rapid expansion from 10 t in 1987 to 1200 t in 1990. The industry however, collapsed to 150 t in 1992, due to inadequate market development (Hecht, 1997). Both species domestication and market development should be public-sector activities because the private sector is unlikely to finance technologies or market development schemes that are broadly applicable and designed to keep as many players as possible, particularly lower-income operations, in business (Corbin and Young, 1997).

Table 3. Development of the aquaculture industry in Israel from 1939 to 1997. Species diversification from 1955 to 1969 was primarily for purposes of polyculture with the principle species, common carp. Increases in efficiency during this period increased competition and led to a major reduction in number of farmers and infrastructure. Changes in government support for aquaculture research and development included increasing the number of species available to investors, which led in the early 1990s to renewed increases in investment. Data from Dill and Ben-Tuvia (1988); Sarig (1989, 1996); and Snovsky and Shapiro (1999). Avg. = average; Ha = hectares; t = metric tons

					Percentage of total production by species or species group						
Year	Number of farms	Total area (Ha)	Average yield (t/Ha)	Total production (t)	Common carp	Cichlids	Mullets	Silver carp	Other carp	Salmonids	Striped bass
1939		15	0.93	14	100						
1941		120	1.07	128	100						
1943		560	1.23	689	100						
1945	30	993	1.26	1,260	100						
1947		1,380	1.64	2,250	100						
1949		2,100	1.76	3,700	100						
1951		2,580	1.49	3,850	100						
1953		2,950	1.58	4,650	100						
1955		3,630	2.01	7,320	98.3	1.6	0.1				
1957		3,640	2.07	7,530	98.6	0.5	0.9				
1959		3,890	2.03	7,990	97.2	0.2	2.6				
1961		4,520	1.96	8,870	96.3	2.6	1.1				
1963		4,900	2.04	10,050	92.2	6.0	1.8				
1965		5,100	2.00	10,180	94.3	3.3	2.4				
1967	88	4,960	1.76	8,680	88.1	8.0	3.9				
1969	83	4,780	2.15	10,260	81.8	11.6	6.6				
1971	84	4,870	2.57	12,530	85.4	8.6	4.1	1.9			
1973	82	4,790	2.88	13,780	83.3	8.1	3.5	5.1			
1975	80	4,457	2.91	12,984	69.8	13.5	3.7	12.9		0.1	
1977	79	4,153	3.24	13,454	60.6	15.7	4.4	19.2	0.1		
1979	77	3,529	3.57	12,619	62.4	21.6	4.7	10.3	1.0		
1981	72	3,425	3.33	11,419	66.4	18.6	6.6	7.3	1.1		

(*Continued*)

Table 3. Development of the aquaculture industry in Israel from 1939 to 1997. Species diversification from 1955 to 1969 was primarily for purposes of polyculture with the principle species, common carp. Increases in efficiency during this period increased competition and led to a major reduction in number of farmers and infrastructure. Changes in government support for aquaculture research and development included increasing the number of species available to investors, which led in the early 1990s to renewed increases in investment. Data from Dill and Ben-Tuvia (1988); Sarig (1989, 1996); and Snovsky and Shapiro (1999). Avg. = average; Ha = hectares; t = metric tons—cont'd.

Year	Number of farms	Total area (Ha)	Average yield (t/Ha)	Total production (t)	Percentage of total production by species or species group						
					Common carp	Cichlids	Mullets	Silver carp	Other carp	Salmonids	Striped bass
1983	61	3,100	3.53	10,936	70.4	19.0	5.2	5.0	0.4		
1985	60	3,034	4.14	12,667	54.0	32.3	6.1	6.4	0.2	1.0	
1987	58	2,775	4.91	13,979	59.7	29.2	3.9	5.3	0.3	1.6	
1989	58	2,863	4.94	14,535	56.3	31.1	6.1	4.3	0.1	2.1	
1991	55	2,887	5.07	15,100	51.9	38.4	5.9	1.4	<0.1	2.4	
1993	56	3,010	4.30	13,540	55.4	31.8	6.1	3.1	0.1	3.5	
1995	55	3,037	5.38	16,341	46.8	36.8	7.9	4.0	0.1	4.1	0.3
1997	72	3,950	5.39	16,671	44.5	37.2	10.7	2.0	<0.1	4.0	1.6

Diversification to support stable industrial development is not a radical idea and has been a component of successful aquaculture development in many countries (Corbin and Young, 1997). (1) Since 1985, Norway has developed successful commercial systems for at least five new species (FAO, 1999). (2) Israel has been steadily increasing the number of species under cultivation (Table 3). Until 1967, when the decline in farm numbers began, the number of species grown on Israeli farms had been three. The decline reversed in 1991, when government increased its role in R, D, & E and encouraged the domestication of new species (Mires, 1995b). By 1993, over 16 species were being cultured (Dill and Ben-Tuvia, 1988; Sarig, 1989, 1996; FAO, 1999) and new investments were being made even while the carp industry was still consolidating (Mires, 1995b). (3) When USA aquaculture was in its infancy and no one knew which technologies were going to prove the most successful, research centers studied at least 16 finfish species (including 8 exotics) for application to USA warm-water aquaculture and numerous others for applications to marine and cold-water aquaculture. (4) In a recent survey of Mediterranean aquaculture, Abellán and Basurco (1999) discovered that 20 marine finfish species are currently under investigation for culture.

Clearly, through use of indigenous species, diversification, and involvement of local interests, low-cost, low-environmental impact, high-quality aquaculture can operate on local scales at productivity levels that benefit local and regional economies. The use of indigenous species for aquaculture should receive far more attention than it does now, particularly in developing countries with abundant potential for domesticating native species.

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