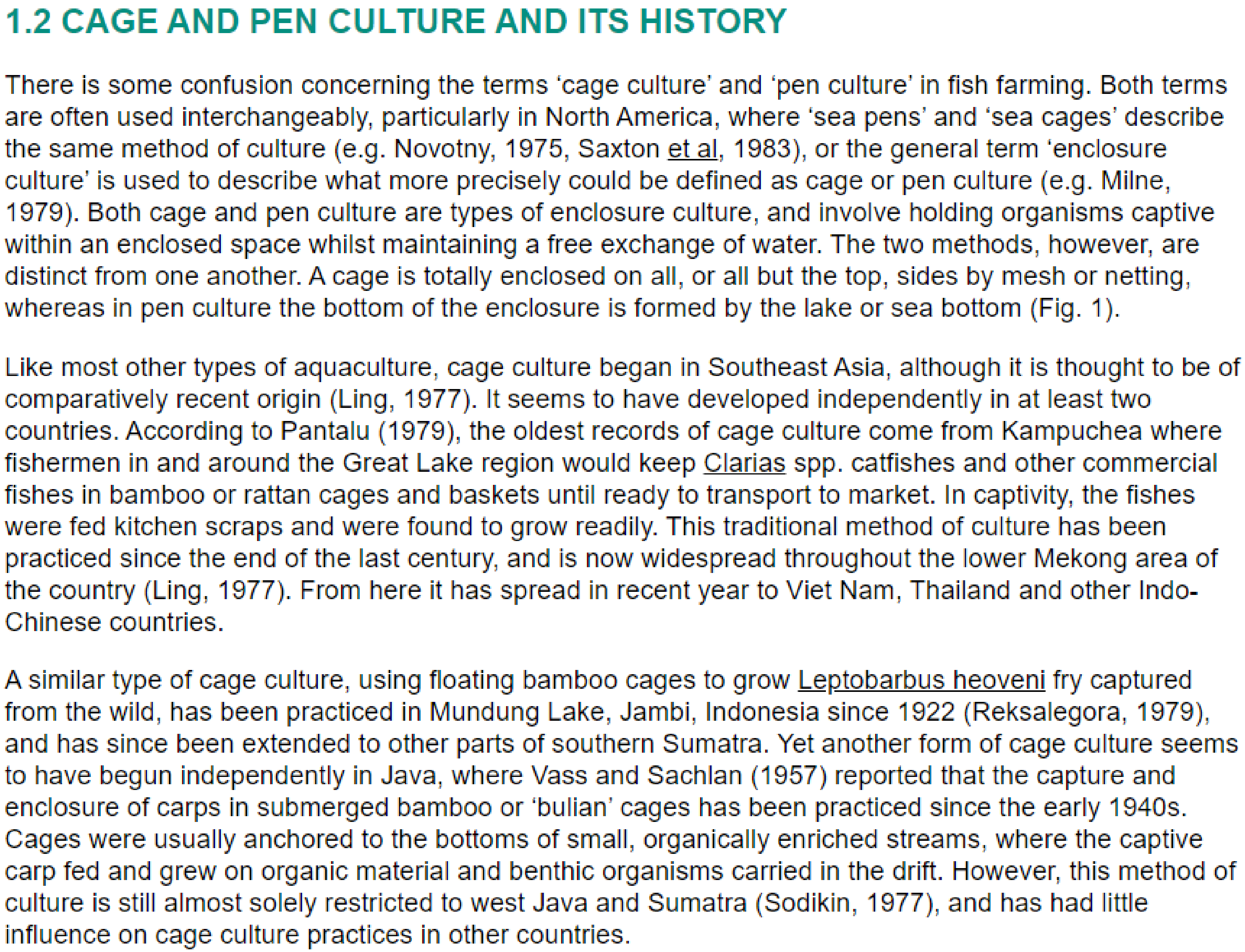
8. Cage culture



1.2 CAGE AND PEN CULTURE AND ITS HISTORY

There is some confusion concerning the terms ‘cage culture’ and ‘pen culture’ in fish farming. Both terms are often used interchangeably, particularly in North America, where ‘sea pens’ and ‘sea cages’ describe the same method of culture (e.g. Novotny, 1975, Saxton et al, 1983), or the general term ‘enclosure culture’ is used to describe what more precisely could be defined as cage or pen culture (e.g. Milne, 1979). Both cage and pen culture are types of enclosure culture, and involve holding organisms captive within an enclosed space whilst maintaining a free exchange of water. The two methods, however, are distinct from one another. A cage is totally enclosed on all, or all but the top, sides by mesh or netting, whereas in pen culture the bottom of the enclosure is formed by the lake or sea bottom (Fig. 1).

Like most other types of aquaculture, cage culture began in Southeast Asia, although it is thought to be of comparatively recent origin (Ling, 1977). It seems to have developed independently in at least two countries. According to Pantalu (1979), the oldest records of cage culture come from Kampuchea where fishermen in and around the Great Lake region would keep Clarias spp. catfishes and other commercial fishes in bamboo or rattan cages and baskets until ready to transport to market. In captivity, the fishes were fed kitchen scraps and were found to grow readily. This traditional method of culture has been practiced since the end of the last century, and is now widespread throughout the lower Mekong area of the country (Ling, 1977). From here it has spread in recent year to Viet Nam, Thailand and other Indo-Chinese countries.

A similar type of cage culture, using floating bamboo cages to grow Leptobarbus heoveni fry captured from the wild, has been practiced in Mundung Lake, Jambi, Indonesia since 1922 (Reksalegora, 1979), and has since been extended to other parts of southern Sumatra. Yet another form of cage culture seems to have begun independently in Java, where Vass and Sachlan (1957) reported that the capture and enclosure of carps in submerged bamboo or ‘bulian’ cages has been practiced since the early 1940s. Cages were usually anchored to the bottoms of small, organically enriched streams, where the captive carp fed and grew on organic material and benthic organisms carried in the drift. However, this method of culture is still almost solely restricted to west Java and Sumatra (Sodikin, 1977), and has had little influence on cage culture practices in other countries.

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1.3 CURRENT CAGE AND PEN CULTURE METHODS

In the last 15 years or so, the practice of cage culture in inland waters has spread throughout the world to more than 35 countries in Europe, Asia, Africa and America, and by 1978 more than 70 species of freshwater fish had been experimentally grown in cages (Coche, 1978a). In all but a few areas, new materials such as nylon, plastic, polyethylene and steel mesh which although much more expensive have a much longer life-span and permit better water exchange, have superceded wood and bamboo. Most designs currently in use are of the floating type, and rely on a buoyant collar constructed either from locally available materials (e.g. wood, bamboo), or from steel or plastic pipe, and from which is suspended a synthetic fibre net. Styrofoam or oil drums are frequently used for supplementary flotation.

Cages are usually floated in rafts, and either anchored to the lake/reservoir/river bottom, or alternatively connected to shore by a wooden walkway (Fig. 2).

In some parts of the world such as China and the Philippines, fixed cages are used in shallow waters (<8m) with appropriate muddy bottoms (FAO, 1983). Synthetic fibre net bags are attached to posts driven into the substrate. They are simpler and cheaper to construct as they don't involve the construction of a buoyant collar, which can account for more than 50% of the capital outlay (see IDRC/SEAFDEC, 1979). However, fixed cages are often poorly constructed, and thus may be less able to withstand adverse weather conditions. For example, in July 1983 almost all of the fixed cages in Lake Buhi, Bicol Region in the Philippines were destroyed by Typhoon Bebeng, whereas most of the floating cages survived.

There are approximately ten species of fish which are commercially cultured in cages in both temperate and tropical waters, and these are listed in Table 1.

The origins of pen culture are more obscure, but it also seems to have begun in Asia. According to Alfarez (1977) and others, pen culture originated in the Inland Sea area of Japan in the early 1920s. It was adopted by the People's Republic of China in the early 1950s for rearing carps in freshwater lakes, and was introduced to Laguna de Bay and the San Pablo Lakes in the Philippines by the Bureau of Fisheries and Aquatic Resources (BFAR) and the Laguna Lake Development Authority (LLDA) between 1968 and 1970 in order to rear milkfish (Chanos chanos) (PCARRD, 1981).

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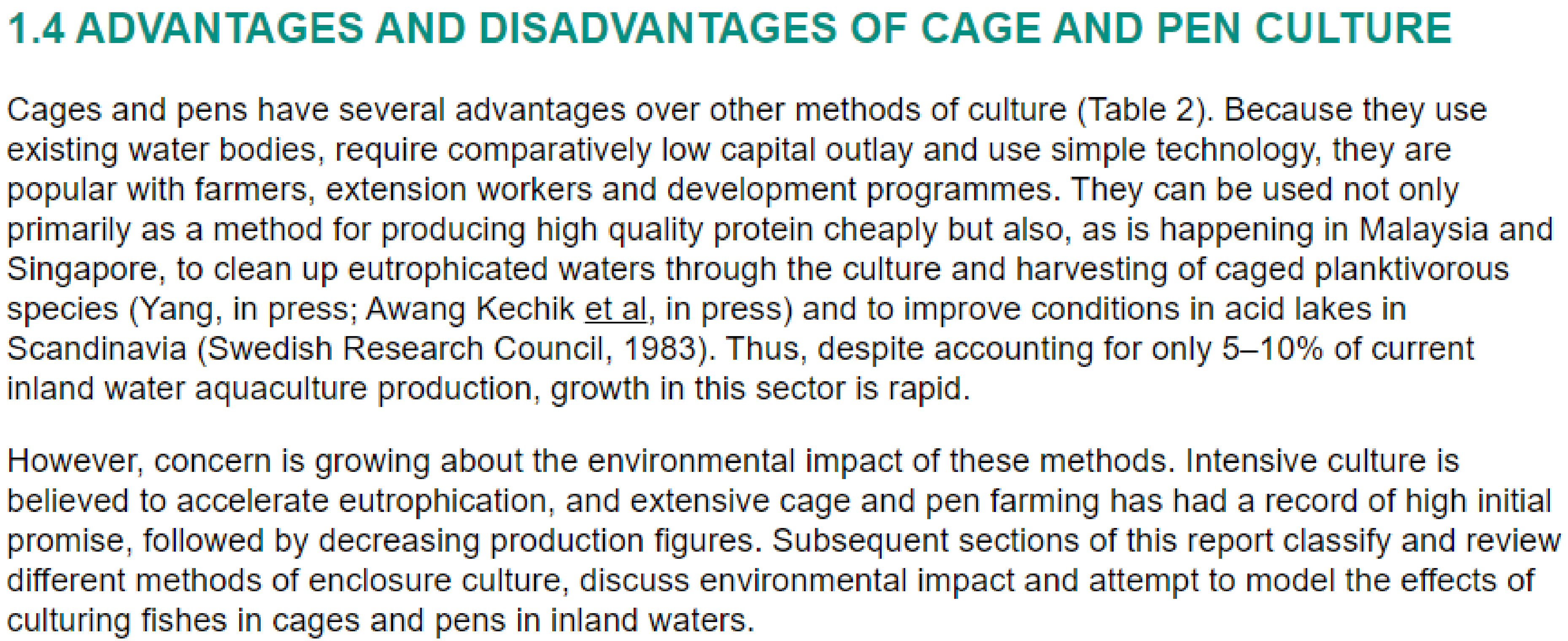

1.4 ADVANTAGES AND DISADVANTAGES OF CAGE AND PEN CULTURE

Cages and pens have several advantages over other methods of culture (Table 2). Because they use existing water bodies, require comparatively low capital outlay and use simple technology, they are popular with farmers, extension workers and development programmes. They can be used not only primarily as a method for producing high quality protein cheaply but also, as is happening in Malaysia and Singapore, to clean up eutrophicated waters through the culture and harvesting of caged planktivorous species (Yang, in press; Awang Kechik et al, in press) and to improve conditions in acid lakes in Scandinavia (Swedish Research Council, 1983). Thus, despite accounting for only 5–10% of current inland water aquaculture production, growth in this sector is rapid.

However, concern is growing about the environmental impact of these methods. Intensive culture is believed to accelerate eutrophication, and extensive cage and pen farming has had a record of high initial promise, followed by decreasing production figures. Subsequent sections of this report classify and review different methods of enclosure culture, discuss environmental impact and attempt to model the effects of culturing fishes in cages and pens in inland waters.

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2.2 LIMITATIONS AND PROBLEMS

There are several factors which demographically restrict the range of species grown and the methods employed. The first constraint is geographic. Primary production, which governs all successive energy transactions in the aquatic food web (Barnes, 1980), has been shown to be correlated with latitude (Brylinsky, 1980). Data derived from the summary report of the 13-year International Biological Programme (IBP) illustrates this (Le Cren and Lowe-McConnell, 1980). Between temperate (23°–67°) and tropical (23°N–23°S) zones, there is a considerable increase in the range of production values (Fig. 3) and thus tropical water bodies offer better opportunities for extensive and semi-intensive cage and pen culture.

In Europe and North America, there are few extensive operations. In the Federal Republic of Germany there is some extensive production of carps in earth ponds (Bohl, 1982). However, extensive cage culture in Europe is largely restricted to the rearing of juvenile planktivorous stages of fishes, using illumination to attract zooplankton (Bronisz, 1979; Uryn, 1979; Jager and Kiwus, 1980). In USA, recent experiments in the extensive culture of bighead carp in cages have proved disappointing, with slow growth and low survival, and thus poor economic prospects (Engle, 1982).

Extensive and semi-intensive methods are only suitable for fish which are planktivorous, or which feed on benthos, detritus or drift, and are not suitable for fish with high protein requirements or which do not have the anatomical, physiological or behavioural adaptations to deal with these types of food. Carnivorous species, such as the salmonids and many of the catfishes (e.g. *Ictalurus punctatus, Pangasius sutchi*) cannot be successfully grown without recourse to intensive methods, using largely fish protein based diets (see Cowey, 1979, for review). Although all of the tilapias have comparatively low protein requirements and many therefore appear suitable for extensive cage culture, this is not so. All tilapias possess both jaw teeth and pharyngeal teeth, and these vary in size, structure and mobility (Trewavas, 1982), thus influencing the type of diet and particle size they can deal with. Microphagous species, such as *O. niloticus*, *O. mossambicus* and *O. aureus* grow better in extensive culture than do the macrophagous species, *T. zilli* and *T. rendalli* (Coche, 1982; Pullin, in press).

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3.2.1 Space

Enclosures can compete with lake and river fisheries for space. Stationary cages and pens, for example, are restricted to shallow areas, which are 7m or less deep, and this approximates to the littoral region of most lakes and reservoirs where rooted emergent and submerged vegetation occurs (Goldman and Horne, 1983). Such areas are important as spawning grounds for commercially important fishes such as the phytophilous cyprinids and pike (Braum, 1978), and the substrate spawning tilapias, *T. zilli*, *T. rendalli* and *O. macrochir* (Ruwet, 1962; Philippart and Ruwet, 1982). Inshore areas of vegetation where predators can be avoided are also important nursery grounds for fry and juveniles of many species.

In Laguna de Bay in the Philippines, pen and cage culture of milkfish and tilapias was introduced in the late 1960s (PCARRD, 1981). Since then these industries have boomed, despite the ravages of periodic typhoons and fish kills (Fig. 5). The LLDA has attempted to regulate the industry and avoid conflict with fishermen and local villagers by trying to limit production within certain areas of the lake designated as a fish pen belt by a series of laws (Republic Act No. 4850, Presidential Decree No. 813, and Resolution No. 9, 1976; Agbayani, 1983). The fish pen belt provides for other interests by leaving free a fish sanctuary area, where no fishing or pens are permitted, and by utilising a 15,000 ha area (17% of the lake surface) which is at least 200m from the shore and yet does not interfere with navigation routes (Fig. 6). Thus access to inshore areas, open waters and fish landing sites should have been protected.

However, in the last 3–4 years, there has been a rapid proliferation of fish pens outside the legal fish pen belt (Figs. 7 and 8). The use of cages to culture tilapia is not covered by existing laws (Agbayani, *ibid*.), and although still of relatively minor importance (100 ha; Guerrero, 1983), they are increasing. Current estimates of the area covered by cages and pens is 34–40,000 ha (38–45% of the lake).

Many of these illegal enclosures were sited in traditional fishing grounds and snail-gathering areas, and blocked the main navigation routes to the fish landing sites (see Fig. 8). In 1982 and early 1983 the widely reported conflict (theft, vandalism, killings) between the local fishermen and the fish pen owners, most of whom live outside the Laguna de Bay area, had escalated. Following public pressure, an aerial survey of the lake was carried out by the Philippine Air Force in April 1983, and when the extent of the proliferating pen industry was realised, existing regulations were enforced.

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3.2.2 Water flow and currents

The flow of water through enclosures is affected by drag forces exerted by the framework and netting (Inoue, 1972; Wheaton, 1977; Milne, 1979; Wee, 1979). The reduction in flow is dependent upon a number of variables including flow rate and density of water, enclosure size and shape, mesh type (knotted/knottless, diamond/square) and material, degree of fouling, and stocking density (Milne 1970, 1979; Inoue, 1972; Wheaton, 1977, Wee, 1979; Kils, 1979). The coefficient of drag (Cd) exerted by knotted and knottless netting is related to nominal mesh size (a), and diameter of twine (d) by the following equations (Milne, 1970):-

$$Cd = 1 + 3.77\,(d/a) + 9.37\,(d/a)^2 \text{ knotted net}$$

$$Cd = 1 + 2.73\,(d/a) + 3.12\,(d/a)^2 \text{ knottless net}$$

Cd is greater for knotted than knottless mesh, and courlene and polythene have smaller Cd values than nylon or ulstron (Milne, ibid.).

Inoue (1972) noted that the current velocity inside a large (20 × 20 × 6m) cage of 5cm mesh size, stocked with fish at 1.6 kg m^{-3} fell to only 35% of the current speed recorded outside the cage, and he also demonstrated that when cages were located parallel to the direction of current, flow rate in successive cages fell.

Cage and pen structures, therefore, can have a considerable impact on local currents, and this has a number of implications. Sediment transportation in an aquatic system, although influenced by a number of factors, is principally determined by current flow (Smith, 1975; Gibbs, 1977). Significant reductions in flow, as can occur in some enclosure systems (see above), would cause the sedimentation of larger, denser particles in the immediate vicinity of the cages and pens. A sudden increase in the rate of sedimentation in an area would disrupt benthic communities (Brinkhurst, 1974) and accelerate filling in (ageing) of the water body, which could interfere with navigation. Siltation in the vicinity of cages and pens has been reported from Egypt, India, Malaysia, Singapore, Sri Lanka and Thailand (IDRC-SEAFDEC, 1979).

Siltation problems caused by enclosures are most likely to occur in rivers and in areas of lakes where large rivers flow in. Here the dispersion of the sediment carrying plume, which is determined by the horizontal water current speed (Csanady, 1969, 1975) could be severely disrupted.

3.3.1 Environmental impact common to all methods of enclosure culture

An enclosure is more of an open fish rearing system than land-based ponds, raceways or tanks, and there is a far greater degree of interaction between the caged or penned fish and the outside environment than occurs in other systems. In recycle systems, only 1–20% of the daily water requirements are replenished (Bryant et al 1980; Muir, 1982; Muir and Beveridge, in press). Incoming water passes through settlement tanks and filtration systems which effectively remove all bacteria, protozoa and plankton, and of course larger organisms such as fish. In some operations, the recycled water is treated by U.V. which kills most of the virus particles and remaining bacteria in the system (Spotte, 1979; Muir, 1982). Thus there is little opportunity for organisms to enter and influence the system from outside, and the fish are cultured in an environment where both the abiotic and biotic components are highly controlled.

In earth and concrete ponds, the fish are fully exposed to the vagaries of climate (sunlight, temperature etc.), and there is also a degree of interaction between the cultured fish and other organisms. Usually, only coarse screens and/or settlement ponds are used, which help prevent fishes (eggs, fry, adults) from entering the system (Hepher and Pruginin, 1981). However, microscopic and macroscopic organisms such as viruses, bacteria and fungi, and phytoplankton, zooplankton and insects can be carried unimpeded into the ponds in inflowing water. Birds and other vertebrates also have relatively free access to ponds and raceways unless elaborate trapping or other preventative methods are used (Meyer, 1981; Martin, 1982).

The establishment of recycle systems and ponds and raceways to grow fish is the creation of a new environment. However water usually only passes through pond and raceway systems once, and the consequences of changes to the water through fish culture is experienced where the effluent is discharged. Outflows from land-based systems of course can be treated by passing water through various settlement pond and filtration systems until acceptable standards are reached (Warrer-Hansen, 1982; Muir, 1982a). By contrast, enclosures use existing environments to grow fish. Cages and pens must thus be regarded as subcomponents of the aquatic ecosystems in which they are sited, since the enclosure and the surrounding environment are intimately related i.e. changes occurring in the water body will have an effect on the enclosure environment, and vice versa. There is little opportunity to treat wastes emanating from cages. Although various methods of waste collection and removal have been developed on an experimental basis (Tucholski et al, 1980, 1980; Tucholski and Wojno, 1980) the costs involved would prove prohibitive to the industry. These differences between land and water based systems have a number of important implications.

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3.3.1.1 Disease

There are five main groups of organism which cause disease in fishes: ectoparasites and fungi, endoparasites, bacteria, viruses and organisms which produce toxins leading to fish deaths (Sarig, 1979). The occurrence of disease outbreaks in fish farming is usually associated with bad husbandry, since the disease-causing organisms are often ubiquitous and cause few problems until the fish are stressed through inadequate dietary or environmental conditions (Wedemeyer, 1970; Snieszko, 1974; Roberts and Shepherd 1974; Shepherd, 1978). In wild fish populations, mass mortalities are rare and are also usually linked to external stress factors (Shepherd, ibid.), since the fish and the disease causing organisms are usually in a state of balance. For example, although many parasitic infections are known in wild tilapias, there is little evidence of clinical effects and thus it would seem that the presence of parasites is a normal occurrence of little significance (Roberts and Sommerville, 1982). Studies of the adult cestode Eubothrium in rainbow trout show that 1–5 parasites per fish have no effect on either nutrient absorption or fish growth (Ingham and Arne, 1973).

However, the introduction of large numbers of fish in enclosures to a system can have a dramatic effect on disease agents. Diseases from outside the enclosure site can easily be introduced by transporting fingerlings/fry from other areas in the country, or importing fish from abroad without proper precautions being taken (Avault, 1981; Mills, 1982). The danger of the spread of fish diseases in this way is widely recognised, and is currently giving cause for concern (Rosenthal, 1976; Roberts and Sommerville, 1982). In a recent survey of the ecto and endoparasite fauna of cage and wild fish communities in a Scottish loch, Sommerville and Pollock (1984 in prep.) have shown that the numbers and species of parasite present in the wild fish differ markedly from expected, and concluded that this was a result of the intensive culture of rainbow trout in the lake. Although some of the parasites may have been imported with fingerlings used in stocking, yet others may have been present in the wild fish and only reached abnormal levels due to increased densities of fish and changes to the environment subsequent to the introduction of cages.

Unfortunately, little is known about the transmission of parasites from cage to wild fish, or vice versa. However, in several cases in the U.K., cage fish have become severely infested with the cestodes Triaenophorus nodulosus and Diphyllobothrium spp. resulting in heavy mortalities, and the eventual closure of one farm (Wootten, 1979; Jarrams et al, 1980). Those infections were attributed to the wild fish populations which were subsequently found to be carrying the parasites.

Data from Matheson (1979) showed that Atlantic salmon parr raised in cages in a freshwater loch in Scotland became heavily infected with D. ditremum and D. dendriticum within two months of being introduced to the site. Surprisingly, the parasites were not isolated from the brown trout (S. trutta) in the loch, although only a few specimens were examined.

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3.3.1.2 Predation

Cages and pens of fish seem to act as a magnet to a wide range of both obligate and facultative fish-eating vertebrates. The range of species reported to cause problems at cage and pen farms is listed in Table 4, and includes fish, reptiles, birds and mammals. Many of these species move into an area where a fish farm has been established, attracted by the large numbers of readily detected fish and also by the bags of commercial feed occasionally left unprotected on the cage walkways. Even comparatively rare species, such as the osprey (Pandion haliaetus) in Scotland will travel considerable distances in order to visit a fish farm. Seasonal and diurnal changes in numbers of predators have been noted (Ranson and Beveridge, 1983).

So far there has been little serious evaluation of the impact of these predators either on the environment, or on the enclosed fish. Ranson and Beveridge (1983) concluded that although herons (Ardea cinerea) and cormorants (Phalacracorax carbo) frequently attacked caged rainbow trout, these attacks were rarely successful. An examination of stomach contents of birds from the farm showed no evidence that any of the fish came from the cages, and this conclusion was supported by many hours of observation. However, 0.5% of all caged fish showed evidence of bird damage, which could lead to secondary bacterial or fungal infection.

Damage to nets by unsuccessful predators such as birds, turtles, monitor lizards and rats has been reported from several cage farms (Table 4), thus contributing to the heavy losses of fish from enclosures reported by Secretan (1979). Predation of wild fish may increase through the attraction of predators to the enclosure site. Ranson and Beveridge (1983) recorded 11 perch (Perca fluviatilis) removed from a cormorant stomach at a cage fish farm. Another serious, although as yet little studied, impact of the immigrant predator population, is their contribution to disease. In the example described in Section 3.3.1.1 above, the rapid spread of Diphyllobothrium to caged rainbow trout within two months of a farm being established may in part be due to the observed migration of large numbers of gulls (Larus sp.) into the area. Certainly both birds and mammals play important roles in the life cycles of many commercially important endoparasitic fish diseases. For example, birds act as intermediate host in the life cycle of the nematode Contracaecum, and piscivorous mammals such as the otter may act as final host for the digenean Haplorchis, both common parasites of tilapia (Roberts and Sommerville, 1982).

3.3.1.3 Wild fish populations

Caged and penned fish frequently escape through netting or mesh damaged by predators, floating objects, or rough weather (Secretan, 1979), and in this way foreign or exotic species can be introduced to an environment. In any commercial cage or pen operation it is inevitable that some fish escape. In one lake in Poland, Penczak (1982) estimated that 4 tonnes of trout escaped in one year. There are many records of the impacts of escaped or deliberately transplanted fishes on indigenous fish stocks, and these include the extermination of local fishes through predation or competition, interbreeding with native fishes and adulteration of the genetic pool, habitat destruction and the outbreak of disease epidemics (Rosenthal, 1976; Mills, 1982).

In Laguna de Bay, typhoons often cause considerable damage to fish pens (PCARRD, 1981). In 1976, 50% of the fish pens were totally destroyed, resulting in the release of millions of milkfish to the lake (Gabriel, 1979). This boosted open water fishery catches tremendously in the weeks following the disaster.

In the U.K., ferral rainbow trout which had escaped from cages were found to be breeding in feeder streams to the lake. Examination of the gut contents showed that the rainbow trout and native brown trout fry in the streams had similar diets, and therefore could be competing. Angling catch returns from the lake demonstrated that brown trout returns, which had declined to a low level many years previously, remained low after the introduction of the cages, whereas the catches of rainbow trout increased each year due to escapes (Phillips, unpublished data).

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