TRANSLOCATION OF AQUATIC ORGANISMS IN WESTERN AUSTRALIA—HISTORY AND IMPACTS

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Summary

This paper discusses the three major impacts of introduced and translocated aquatic organisms—genetic diversity, pathogens, and ecosystem conservation—in relation to costs and benefits to the community and the Western Australian environment. The current status of aquatic organisms that have been introduced or translocated to Western

Australia is discussed by species and degree of the aforementioned impacts. The net impact of introductions has ranged from species becoming feral pests like gambusia or carp, to species contributing to commercial industries such as *Artemia* or trout.

Escape of aquatic organisms from enclosures is seemingly inevitable. Consequently, introduced or translocated species held in culture establishments potentially present the same problems as a wild release. A supporting review of the history of species previously introduced into Western Australia—carp, goldfish, tilapia, and yabbies—shows that these species, although originally destined for enclosed or isolated environments, have now established feral populations in natural waterbodies.

Introductions are often permitted due to the demands of interest groups, such as recreational fishermen, aquaculturists, or aquarists. Conversely, conservation bodies generally advocate the maintaining of pristine ecosystems. Greater public education of the problems, dangers, and costs incurred by introductions, along with controls and penalties is required to ensure that unauthorized introductions and translocations are limited. Proponents of future introductions, whether government or private, should recognize the potential implications of their actions.

1. Introduction

The introduction and translocation of aquatic organisms has received considerable attention from community groups in Western Australia, particularly with regards to the stocking of nonindigenous species for aquaculture and recreational fishing. Although the physical transport and acclimation of introduced and translocated species is a relatively simple process; there are a number of issues that require thorough consideration prior to any such action. In order to assist in evaluating proposals to introduce aquatic organisms, this paper discusses the three main negative impacts of introduced and translocated aquatic organisms:

- genetic diversity
- pathogens, and
- ecosystem conservation.

Additionally, the potential costs and benefits of introducing or translocating selected species are discussed.

The Western Australian aquatic environment is relatively unique due to a number of factors. First is the large geographic area of the state, which covers a range of environments from temperate to arid desert, Mediterranean, and tropical. Consequently, the risks associated with introducing an aquatic organism may vary significantly according to the proposed region and the environmental requirements of the candidate species. The second factor is the absence of shared waterways such as rivers, canals, or lakes with other states or countries. In addition, a significant proportion of Western Australia's state border consists of desert. Consequently, Western Australia is not subject to either the exchange of aquatic fauna or the introduction of exotic species via shared waterways and is thus, to a large extent, not subject to the uncontrolled introduction of aquatic organisms. The third factor is the Leeuwin Current, which originates in the tropics and flows southwards along the Western Australian coastline. It has extended the natural southerly distribution of many tropical species. It is also possible that the Leeuwin Current may limit the introduction to Western Australia of marine temperate species due to its warming influence and low productivity. The probability of introduced temperate marine aquatic organisms becoming established in Western Australia is greater in estuaries where water temperature is less influenced by the Leeuwin Current and higher productivity results in more favorable conditions.

Prior to discussing the issues involved with the introduction and translocation of fish, crustaceans, and molluscs, it is prudent to clearly identify relevant terminology. Relevant definitions are given in the Glossary.

Introductions or translocations may occur either accidentally or on purpose, either with or without government approval, for a number of reasons, including enhancement of recreational fishing, enhancement of commercial fisheries, biological control, escape of aquaculture stock, escape or release of aquarium fish, use of live bait, and transmission of aquatic organisms via water (as in bilge water, floods, rivers, or canals).

Consequently, accidental introductions may in many cases be contained by the distribution of natural waterways. However, accidental introductions only account for ~10% of species translocated worldwide. The intentional introduction of aquatic species, whether authorized or unauthorized, may result in a greater spread of species throughout unconnected waterways.

It has been widely reported that translocation of nonindigenous fish has the potential to cause ecological imbalance and may endanger local indigenous fish species, due to a number of factors. In most circumstances, although translocated fish have resulted in adverse consequences or have had unexpected consequences upon native populations, they have generally had poor success in achieving the intended goals for which they were originally introduced. This is despite a number of notable exceptions including carp and rainbow trout; both of which have developed into successful industries after introduction to Europe; and the widespread introduction of tilapia farming in developing countries. While other introductions have had both positive and negative impacts such as the introduced European mussel which is both a fouling organism and supports an aquaculture and wild-capture fishery in Western Australia.

2. Introduction and Translocation Issues

- The main factors of concern regarding the introduction and translocation of aquatic organisms are their potential impact upon genetic diversity, the introduction of pathogens, and their effect on ecosystems including the establishment of feral populations and their impact on indigenous aquatic species.

2.1. Genetic Diversity

The major concern over the introduction of new genetic material into a population is the potential effect upon genetic integrity. Indigenous species have evolved over a substantial period of time in order to survive in the host environment and it may not be possible to recover this genetic material once it has been lost or compromised.

Genetic diversity may be decreased through interspecific and intraspecific hybridization, or through mixing of genetically discrete strains. The introduction or translocation of strains, genetically discrete stocks, species, and in some cases genera, that are capable of interbreeding with existing populations can have several potential consequences.

Existing strains of species may differ between isolated waterbodies. Consequently, the mixing of strains may limit genetic integrity that has been developed over an extended period of time. Furthermore, the introduction of species or genera that can interbreed may result in the establishment of hybrid populations, which in some cases, due to heterogenesis, may prove genetically superior to existing stocks.

Some crosses can result in sterile hybrids which, depending upon the specific case, may prove either an advantage or disadvantage. Concern has also been expressed over the potential impact from the escape or introduction of transgenic aquatic organisms that contain cloned genes from other species.

Internationally, the most widespread case of interspecific and indeed intergenera hybridization has occurred among species of the Tilapiine family, commonly referred to as tilapia. It is now well established that, due to extensive hybridization, pure strains of tilapia are difficult to obtain. This has created difficulties for developing aquaculture industries that rely upon interspecific crosses, such as *Oreochromis mossambica* females × *Oreochromis macrochir* males, to obtain single sex stocks; or for breeding programs, such as development of the higher value, faster growing, red tilapia by crossing female hybrids of *Oreochromis mossambica* × *Oreochromis hornorum* with *Oreochromis nilotica*.

Some species may be eliminated due to hybridization and/or competition. In some cases not only the original species may disappear, but also the hybrid as it may be less able to withstand the natural variations within the environment.

Specific cases in which the above situations have occurred include the introduction of *Oreochromis leucostictus* in 1956 to established populations of *Oreochromis spilurus* in Lake Naivasha, Kenya. This resulted in hybridization between the two species and subsequently the disappearance of *O. spirulus* initially and, at a later date, disappearance of the hybrids. Similar cases have occurred elsewhere including the disappearance of *O. macrochir* after hybridizing with *O. niloticus* in Lake Itasy; *O. esculentus* and *O. variabilis* after hybridising with *O. niloticus* and *T. zilli* in Lakes Victoria and Kyoga.

Because there are no indigenous representatives of the families that have been introduced, Australian aquatic fauna has not experienced the adverse consequences of translocation-induced hybridization as described above. However, the importation of species such as rainbow fish, barramundi, or *Macrobrachium* sp. from countries with similar aquatic fauna, such as Papua New Guinea or South–East Asia, may result in negative impacts similar to those outlined above due to hybridization with indigenous species.

There are examples in Australia of hybridization between imported varieties of *Cyprinus carpio*; between *Cyprinus carpio* and *Carassius auratus*; and between *Oreochromis mossambicus* and *O. hornorum* or *O. niloticus*. The hybridization between two varieties of European carp in eastern Australia produced the Boolarra strain, which has spread more rapidly than previous stocks. In addition, the illegal translocation of the tilapia hybrid, which is regarded as a noxious species both within Queensland and between Queensland and New South Wales, has caused concern.

Concern has been expressed over the mixing of barramundi (*Lates calcarifer*) stocks in Australia. Scientists have identified seven distinct strains of genetically discrete stocks of barramundi from the north of Australia. The mixing of these strains due to aquaculture, recreational fisheries enhancement or restocking, may reduce the naturally occurring genetic diversity essential for any future selection program.

To minimize the genetic effects of introductions upon natural populations, apart from those arising from direct competition of escaped fish with natural populations, infertile introduced species may be utilized, thus preventing hybridization or the establishment of feral populations. The induction of triploidy has been utilized to produce infertile aquatic species, this also benefits farmers, as triploids generally grow faster, after the usual age of sexual maturity, than diploid animals.

One method of preserving genetic diversity is cryopreservation. Cryopreserved gametes may be held in suspension for extended periods then regenerated later to re-establish populations. Cryopreservation of gametes has been used to conserve genetically discrete stocks and endangered species.

2.2. Pathogens

Introduced or translocated aquatic organisms may contain pathogens detrimental to indigenous species. This is particularly relevant to the translocation of aquatic species from regions of known pathogen occurrence to disease-free environments, where indigenous stocks have not had the opportunity to develop immunity to the introduced fungus, parasite, bacteria, or virus. Conversely, in cases where translocations are encouraged to develop a resource, the translocated fish may succumb to existing pathogens not previously encountered in the region from which they originate.

The transfer of disease-causing organisms has occurred in parallel with the translocation of aquatic species worldwide. In a number of cases the introduced organism may be more pathogenic for the local species than for the original host. Examples of this are the transfer of the crayfish plague fungus *Aphanomyces astaci* to Europe (generally attributed to the translocation of the North American crayfish *Orconectes limnosus*), which has devastated the European crayfish (*Astacus astacus*) industry. Although American crayfish are less susceptible to this fungal infection, it is invariably fatal to the European crayfish, and has severely damaged an important fishery and aquaculture industry. This is certainly not an isolated example.

Swimbladder nematodes (*Anguillicola crassus* and *A. novaezelandiae*) were translocated with live eels from Asia and New Zealand, to eel populations in Europe, proving more pathogenic to the local species than to the original host. East Asian herbivorous carps introduced the cestodes *Bothriocephalus acheilognathi* and *Khawia sinensis* to Europe, and these are now the most significant pathogens in cultured carp stocks. Anchor worm (*Lernea cyprinacea*) and lice (*Argulus foliaceus*) have been transferred internationally in carp. *Gyrodactylus salaris* transmitted to Norway by salmon smolts from Sweden in 1975 may threaten wild Atlantic Salmon populations in Norway. Transferal of *Bonamia ostreae* from California to the rest of North America, Europe, and the UK has had severe economic consequences for the flat oyster industries of all countries affected. IHNV (infectious haematopoietic necrosis virus) from stock in Alaska has been introduced to wild and cultured salmon populations in Japan.

In addition to transfer by aquatic organisms, a number of pathogens have demonstrated the ability to vertically transmit disease via eggs, sperm, or embryos, such as IPNV (infectious pancreatic necrosis virus), IHNV (infectious haematopoietic necrosis virus) and BKD (bacterial kidney disease).

Even with the adoption of health testing standards, certain pathogens such as IHHN (infectious hypodermal and haematopoietic necrosis) of penaeid prawns, which has spread via live transfers from Central America to the United States, Israel, and other countries, may still be translocated due to the existence of carriers and the difficulties involved with detection.

Indirect infections such as the algal blooms created by the dinoflagellate *Gymnodinium* sp. have been translocated to North America and more recently Australia. The introduction of *Symnodinium* has been attributed to transmission in ballast water and sediment discharge. The algal blooms have had significant economic and human health repercussions for fish and mollusc farms.

The translocation of fish species into Australia has been responsible for a number of disease introductions. Of large-scale economic importance has been the introduction of *Aeromonas salmonicida* via goldfish in the 1970s. While not only causing GUD (goldfish ulcer disease) in wild and cultured goldfish and carp populations, this pathogen may also affect salmonids and, consequently, it is a major economic threat to salmon farmers. In response, Tasmania initially prohibited the import of goldfish, and currently all goldfish imported to Tasmania must be certified free of *Aeromonas salmonicida*. These measures were introduced in an effort to protect the state's developing aquaculture industry.

In Australia, translocated fish have also introduced the crustacean parasites *Lernea* and *Argulus* to indigenous fish populations. In common with *A. salmonicida*, *Lernea* and *Argulus* affect the aquaculture industry and, in some cases, are responsible for costly eradication and control procedures. Similarly, the introduction of white spot, *Icthyophthirius multifiliis*, with salmonids in the 1930s results in a protozoan infection causing high mortalities and subsequent expense to fish farmers and aquarists throughout Australia.

Concerns have been expressed over translocations within Australia, with regards to EHNV (epizootic haematopoietic necrosis virus). This virus was initially described in the introduced redfin perch in 1986 and has subsequently spread to trout. EHNV has since been demonstrated to have a pathogenic effect upon a number of native fish including silver perch, Macquarie perch, and mountain galaxias. Victoria and Western Australia have now banned the translocation of redfin perch.

Similarly, the spread of the coccideans *Eimeria* and *Goussia* from hatchery populations of Australian native fish such as silver perch, Murray cod, and golden perch to existing uninfected wild stocks may be of concern to future restocking or translocation programs. The translocation of rock oysters has already spread disease resulting in higher winter mortalities along the eastern coast of Australia.

In 1988, renowned fisheries pathologist Dr. Jeremy Langdon presented a thorough review of existing imported diseases to Australia and pathogens that are at risk of importation.

The establishment of hatcheries with disease-free broodstock will reduce the continued risk of pathogen transfer associated with introducing or translocating aquatic organisms. This permits the domestic production of disease-free aquatic species required for recreational or commercial enterprises, rather than the continued expense and risk associated with importing new animals.

2.3. Ecosystem Conservation

The introduction of aquatic organisms may lead to the extinction of indigenous species either directly through predation or competition, or indirectly by altering the existing environment or impacting on the food chain at a different level. Ecosystem alterations will usually occur to the detriment of indigenous populations. This has a more far-reaching effect than the impact of predation or competition, as it affects the entire aquatic community rather than only immediate prey or competitor species. According to the trophic cascade theory, the introduction of an aquatic species that consumes zooplankton may result in decreased water clarity, creating an unsuitable hunting environment for ambush predators. Conversely, introduction of phytoplanktivores may lead to an increase in water clarity, reducing the competitive effectiveness of tactile, or low light, foragers. Therefore, introductions can indirectly result in altered levels of predation, eutrophication, and deoxygenation (with resultant fish kills), or directly result in habitat changes which favor or limit specific aquatic organisms, due to their trophic level.

The effects of ecosystem alterations due to translocation have been demonstrated in Europe, where herbivorous grass carp have directly affected the availability of macrophytes and phytoplankton. The resulting alterations in food composition and availability, and the removal of aquatic plants upon which pike and common carp species rely for reproduction, have significantly decreased fish yields. In Australia, the effect of introduced poeciliids such as gambusia and guppies upon aquatic macrophytes required by rainbow fish (*Melanotaenia* spp.) as spawning habitats has been attributed as the cause of a decline in this native species.

In addition to trophic level alteration, species such as common carp introduced into Africa, the United States, and Australia have directly affected ecosystems through the mobilization of bottom sediments, resulting in the elimination of aquatic flora critical to ecological stability.

In Australia, the decline of indigenous fish in the presence of introduced species has also been attributed to competition for similar food items. Declining numbers of native freshwater catfish (*Tandanus tandanus*) and silver perch (*Bidyanus bidyanus*) are partly due to competition by feral populations of common carp (*Cyprinus carpio*).

Introduced species may also predate upon existing fauna. The introduction of Nile perch (*Lates niloticus*) into Lake Victoria and Lake Kyoga provides a classic example of the potential of a piscivore to decimate existing indigenous species. Prior to the introduction of Nile perch into these lakes, 80% of the demersal fish stocks consisted of haplochromines, which were the most abundant fishes in the lakes. After the introduction of Nile perch in the 1950s and 1960s, haplochromine stocks decreased rapidly and are now extremely rare in Lake Victoria and Lake Kyoga. The loss of the Lake Victoria haplochromine species is significant both in terms of a depleted artisinal fishery and ecologically, as they included over 300 endemic species, which contributed much to our understanding of evolution and adaptive radiation.

The evidence of decreased endemic species due to the introduction of a piscivore is also apparent in Australia, where the Lake Eacham rainbow fish (*Melanotaenia eachamensis*) has diminished in the presence of unauthorized translocations of the mouth almighty (*Glossamia aprion*) and the archer fish (*Toxotes chatareus*). Further, the poeciliid *Gambusia holbrooki* has been responsible for, not only environmental changes as previously discussed, but also direct predation upon eggs and fry of native rainbow fish (*Melanotaenia duboulayi*), crustaceans, and molluscs. Other poeciliids introduced to Australia like the guppy (*Poecilia reticulata*) and one-spot live bearer (*Phalloceros caudimaculatus*) are less aggressive than gambusia, however, where they are present endemic fish species are rare. Other introduced fish, such as brown trout (*Salmo trutta*) and redfin perch (*Perca flaviatilis*), have been reported to affect the numbers of galaxiids, pygmy perch (*Nannoperca australis*), and golden perch (*Macqaria ambigua*), by feeding on small fish and fry. In Western Australia, native crayfish (koonacs, marron, gilgies) are major food items for both trout and redfin perch.

Although not directly causing mortalities, the fin nipping behavior of fish, such as the introduced gambusia, can inflict lesions that make endemic species more susceptible to disease. It has also been suggested that on occasion, where a feral population establishes, the sheer numbers may adversely affect, and in the specific case of introduced *Gambusia holbrooki* and *Xiphophorus helleri*, stress native fish.

The impact of mankind upon existing waterways, particularly, the construction of reservoirs, and industrialization, may have a greater effect upon native fish populations and their ecosystem than that of introduced aquatic organisms, with the exception of piscivores or introduced disease-causing organisms. Furthermore, the effects may not be entirely detrimental. There are a number of documented cases where introduced fish populations have not decreased indigenous fish populations, and significantly, in some cases native fish yields have increased with the introduction of herbivorous fish species.

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Biographical Sketches

Craig Lawrence has a Bachelor of Applied Science from Edith Cowan University, a Post Graduate Diploma in Natural Resources (majoring in Marine Biology and Aquaculture) from Curtin University of Technology, a Master of Science in Aquaculture from the internationally recognized University of Stirling (in Scotland) and completed his PhD with the University of Western Australia. Craig has received a number of academic awards including a Rotary Foundation scholarship, Planet Earth Scholar, MSc thesis prize, and is a Chartered Biologist. Craig has extensive international aquaculture experience including commercial fish farms, universities, and research institutions in the UK, Europe, USA, Middle East, Japan, Taiwan, and Singapore. Since 1992, he has been employed as a Senior Research Scientist in Aquaculture with the Department of Fisheries in Western Australia, where he has provided advice to the developing finfish aquaculture industry and developed a freshwater crayfish research program.

Glen Whisson has a Bachelor of Business in Marketing, a Post Graduate Diploma in Natural Resources, and a PhD from Curtin University of Technology. Glen received a Chancellor's commendation for the excellent quality of his doctoral dissertation, which investigated commercial crayfish polyculture in Western Australia. Glen was Founding President of The Silver Perch Association of Western Australia (1995–2000) and is current President of International Association of Astacology, having served on its Executive Board since 1996. He has lectured in aquaculture and related disciplines at Curtin University of Technology since 1992 and is now Research Director of the Aquatic Science Research Unit.