

Management of invasive freshwater fish: striking the right balance!

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ABSTRACT

Management of invasive species is integral to the maintenance of freshwater environments. Habitat protection alone will not protect the full range of indigenous communities or ecosystem services. It is also contentious as it may involve removal of valued introduced sport fishes. An invasive fish can be defined as any species that significantly adversely affects the long-term survival or genetic variation of native species, or the integrity or sustainability of natural communities. Implications for sport fish, particularly trout, must be considered within the context that they are valued by the public, have statutory protection, and their presence contributes to conservation of New Zealand's fresh waters. Standard pest management criteria also demonstrates that widespread management of some sport fish species is likely to be neither socially acceptable, nor technically or fiscally feasible. Nevertheless there will be circumstances under which management will be required. Invasive fish may also include exotic fish that threaten valued introduced species, or impact upon waterway condition and services. The continued spread of introduced species indicates that management of invasive fish requires urgent attention and a coordinated multi-agency approach. Any response should draw upon established terrestrial pest management frameworks, and the experience of terrestrial pest operations (national and international), island eradications and international fishery restoration programmes.

1. INTRODUCTION

In developing the workshop on invasive species I was aware that there were a number of people who questioned the need for a workshop on pest fish. Land-use impacts on streams and loss of habitat were seen by many to be a much higher priority. Equally, concerns were also raised about the implications of considering highly valued introduced salmonid species as 'pest' fish, as there is a strong public sector interest in maintaining these sport fisheries even though they are based upon introduced species. The debate was highlighted during the consultation phase of the New Zealand Biodiversity Strategy. Sport fisheries advocates voiced concerns that any management of these sports fish to protect native communities was just the 'thin edge of the wedge' of a process that aimed

to eradicate trout (in particular) from New Zealand. These concerns indicated there was a need to justify the focus on invasive fish as a threat to New Zealand's indigenous biodiversity, and also to provide a pest management context for valued introduced species. The challenge was how to strike the right balance between maintenance of indigenous biodiversity, and sport fisheries.

2. WHY FOCUS ON INVASIVE SPECIES?

The New Zealand Biodiversity Strategy sets out a clear goal for freshwater management agencies to maintain, protect and enhance the condition and extent of natural freshwater ecosystems and species (Anon. 2000). Historically, New Zealand's freshwater management has focused upon aspects of habitat protection including site protection, riparian management, restoration of fish passage, avoiding and remedying point source pollution, harvest management and maintenance of minimum flows. However, habitat protection alone will not ensure the maintenance of indigenous freshwater biodiversity, and below are three examples to illustrate this point.

The Whangamarino Swamp is a Ramsar wetland of international significance. At 7290 ha, it is the second largest swamp and bog complex in the North Island. The Department of Conservation (DOC) is actively managing terrestrial weeds. Willow control trials are being undertaken to reverse grey willow (*Salix cinerea* ssp.) invasion from over 1700 ha of the wetland, and an estimated \$1.3 million has been spent on construction and reconstruction of a weir to reinstate historic water levels. However, below the water surface, the wetland contains *Gambusia affinis*, perch (*Perca fluviatulus*), koi (*Cyprinus carpio*), rudd (*Scardinius erythrophthalmus*), and catfish (*Ameiurus nebulosus*) that will have potentially irreversibly compromised native macrophyte, invertebrate and fish community values.

To the south of the Whangamarino, Lakes Rotomanuka and Serpentine are two of the least modified peat lakes in the Waikato region. The Serpentine lakes are the last remaining Waikato peat lakes free of introduced macrophytes. The complex is listed as a nationally significant wetland in the wetlands in Oceania of national importance (Cromarty & Scott 1996). The lakes' riparian margins are fenced, terrestrial weed control including willow removal has begun, native plantings around the perimeters have been undertaken and the regional council has initiated controls to try to limit nutrient inputs. However, both lakes have been invaded by catfish and rudd. In Rotomanuka, macrophyte collapse has occurred at 1–4 m depth, and there appears to have been changes in the phytoplankton assemblage (G. Barnes, pers. comm.). A similar process appears to be underway in the Serpentine lakes. The relative role of rudd versus increased nutrient concentrations is unclear, but dieback is consistent with the effects demonstrated by de Winton et al. (present volume). The presence of introduced fish will have compromised the integrity of these systems, and had affects upon native invertebrate and fish communities.

Finally, in the South Island, Lake Christabel at 270 ha was the largest New Zealand lake free of exotic fish. The lake is one of only three freshwater faunistic reserves in New Zealand. It was protected for its near pristine state,

abundant koaro (*Galaxias brevipinnis*) populations and absence of introduced species (Johnson et al. 1976; Cromarty & Scott 1996). The entire catchment is within a protected ecological area, nested inside a conservation park and it is therefore physically isolated from development—arguably, the ultimate in habitat protection. However, brown trout were recently discovered in the lake and appear to have colonised some time around 1996 (Gerbeaux, pers. comm.). Anecdotal evidence from central North Island lakes (McDowall 1990) suggests that if trout successfully establish they will have a significant negative impact upon the koaro populations. Implications for the rest of the freshwater communities are unknown.

Hopefully these examples illustrate that maintenance of New Zealand's freshwater biodiversity will require integrated management including the management of invasive freshwater species. Invasive species do not recognise reserve boundaries, and once they are established, the absence of suitable eradication tools ensures their impacts are not readily reversible. Dean (present volume) showed that New Zealand is going through a second wave of exotic fish introductions. These started with the illegal introduction of rudd and koi carp in the 1960s (McDowall 1984, 1990), followed in recent years by the active dispersal of these species, and introduction of orfe. These species are colonising low elevation, low gradient waterways—systems already heavily modified (Winterbourn 1987), and poorly represented within the conservation estate, but likely to contain important components of New Zealand's biodiversity.

In contrast to an increasing pest fish problem, most major habitat loss has already occurred and the Resource Management Act 1991 establishes rules that 'should' ensure that further large-scale destruction of remaining natural systems will not occur. This effects-based legislation was designed to ensure the impacts of sediment, contaminants, abstractions, drainage, flow modification and barriers are avoided, remedied or mitigated. Remedial solutions to many of these problems are either available and/or there are current research projects working on potential answers. Arguably many of these impacts are reversible with regards to restoring riparian communities and water quality, preventing the discharge of contaminants and allowing for upstream/downstream passage. The Resource Management Act has also been the catalyst for habitat creation and restoration projects as part of consent mitigation packages. Finally, there is also wide public recognition of the need for habitat protection. Water pollution and habitat destruction are not generally socially acceptable.

In the last 20 years there has been a small improvement in freshwater ecosystem health particularly in the form of reductions in point-source pollution, treatment of farm effluent, improved forestry practices and sewerage treatment (Taylor & Smith 1997; Scarsbrook et al. 2000). However, intensification of farming practices and, most noticeably, the increase in dairy farming in the South Island have the potential to reverse these trends (Parkyn et al. 2002). There has been no improvement associated with the spread of pest fish species. There is poor community appreciation of the problem and a limited ability to reverse introductions. Therefore I believe invasive fish pose one of the most pressing threats to the long-term survival of New Zealand's indigenous biodiversity, and it is one that we cannot continue to ignore.

3. DEFINING AN INVASIVE FISH SPECIES

Owen's (1998) definition of a plant pest is adapted as follows: 'An invasive fish is any species that can significantly adversely affect the long-term survival of native species, the integrity or sustainability of natural communities or genetic variation within indigenous species.'

This means an invasive species may include native and game fish species. For example, koaro (*Galaxias brevipinnis*), a nationally threatened species (Tisdall 1994), is a potential pest. In some Otago locations it has invaded waterways above artificial impoundments or headwater catchments via water diversion races (McDowall & Allibone 1994) and is excluding non-migratory galaxiid species. Water diversions have also facilitated inter-catchment movement of previously isolated non-migratory species leading to hybridisation (Esa et al. 2000). Because of the altered genetic integrity of these previously separate species, the hybrids and the artificially introduced non-migratory native galaxiids would be considered pests.

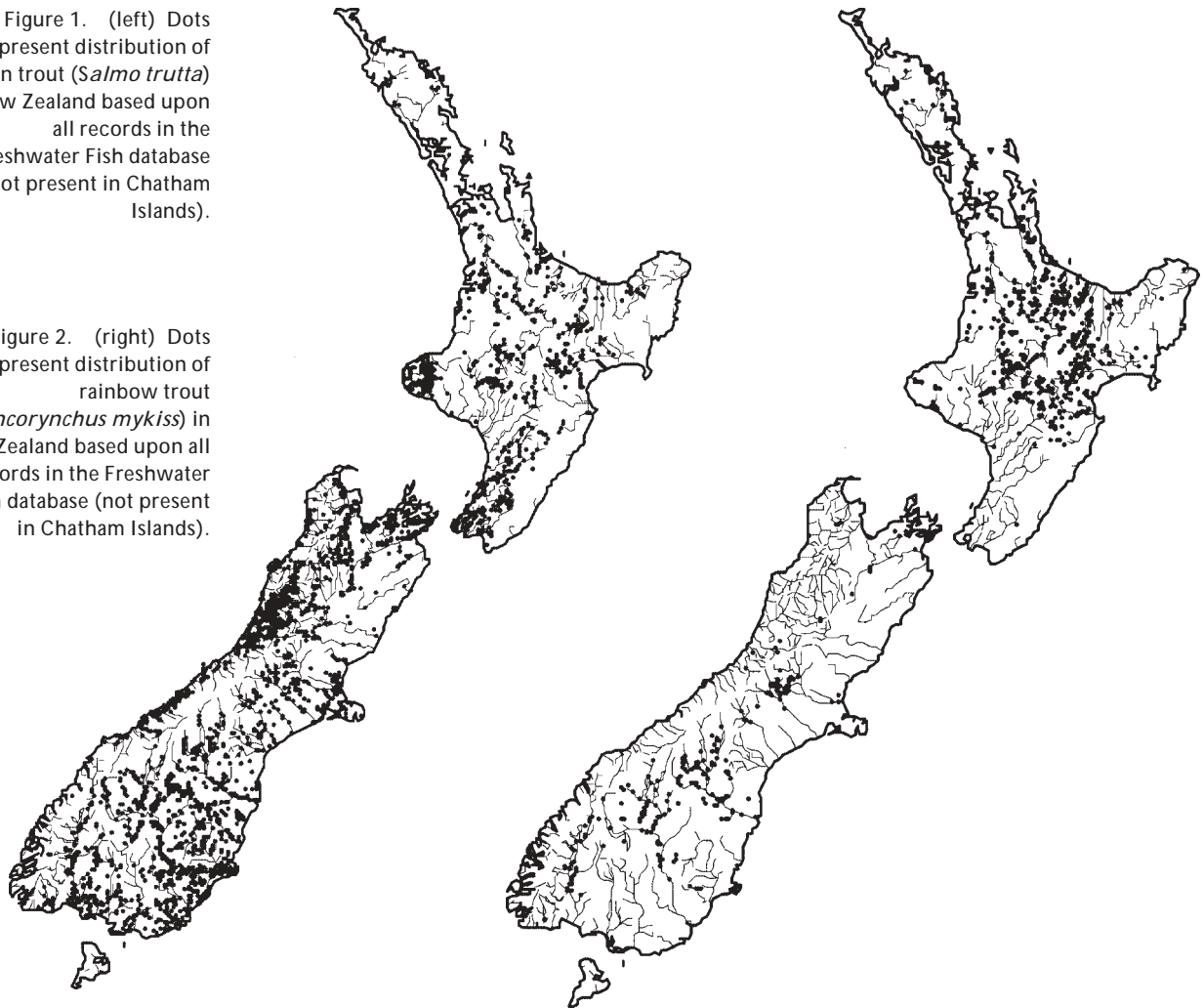
Invasive species will also include sports fish like introduced salmonids. Arguably, New Zealand's single most successful freshwater fish invaders have been brown (*Salmo trutta*) and rainbow (*Salmo salar*) trout (Figs 1 and 2). There is little doubt that these species have had significant and ongoing impacts upon native freshwater communities in New Zealand as they have elsewhere in the world (Crowl et al. 1992). The impacts upon the non-migratory galaxiids in Otago (Townsend & Crowl 1991; McIntosh et al. 1994) and more recently Canterbury (McIntosh 2000) have been well documented. Trophic changes resulting from predation of invertebrate grazers have also been demonstrated (McIntosh & Townsend 1996). Finally, there is also circumstantial evidence of negative interactions between trout and the other large galaxiids (Taylor & Main 1987; Main 1988; Taylor 1988; Chadderton & Allibone 2000), although the impacts of habitat loss and degradation and an absence of pre-introduction data makes this hard to prove scientifically.

These highly prized sports fishes have also had significant secondary spin-offs for freshwater conservation. The maintenance of salmonid fisheries has been central to a number of water conservation orders (Taylor & Smith 1997), establishing sustainable environmental flows (Jowett 1992) and general streamside habitat and water quality protection. In addition, fishing-based tourism is a significant part of the New Zealand economy and generates large sums of tourism revenue. For example, fisheries related expenditure in the Taupo district alone was estimated at \$16.7 million in the early 1980s (Shaw et al. 1985). There is a clear social interest in the maintenance and enhancement of these fish species, which is reflected in crown statutes. For instance, s. 6(ab) of the Conservation Act 1987, and s. 7(b) of the Resource Management Act 1991 require DOC and local government agencies, respectively, to have specific regard to the preservation of trout and salmon fisheries and habitats.

Introduced fisheries' goals and maintenance of indigenous biodiversity are not necessarily mutually exclusive, and there is much commonality of interest between managers of introduced and native fish species. Nevertheless, time and resources have been wasted in debates over perceived conflicts of interest, particularly with regard to brown and rainbow trout fisheries. The reality is that

Figure 1. (left) Dots represent distribution of brown trout (*Salmo trutta*) in New Zealand based upon all records in the Freshwater Fish database (not present in Chatham Islands).

Figure 2. (right) Dots represent distribution of rainbow trout (*Oncorhynchus mykiss*) in New Zealand based upon all records in the Freshwater Fish database (not present in Chatham Islands).



trout in New Zealand are here to stay and their presence will continue to have positive benefits to the maintenance of habitat quality and upstream/downstream linkages—two prerequisites for the maintenance of indigenous freshwater communities.

Widespread 'pest' management of salmonids is neither practical nor fiscally or socially acceptable, and this can be demonstrated by assessing these species within plant and vertebrate pest frameworks. Brown and rainbow trout do not fit the criteria (Owen 1998) (Figs 3 and 4) for a 'pest led' species because they are widespread, well established and have consolidated their presence within New Zealand. Furthermore, in most rivers or lakes of any size they would fail to meet eradication criteria (Table 1 after Owen 1998, Bomford & Tilzey 1997).

There will be sites where the Department will want to eradicate salmonids species because they pose a significant threat to the maintenance of a threatened species or ecosystem. Practically, however, this will probably be in small water bodies that are suboptimal habitat for salmonids, and where these fish do not contribute to the fishery or the stream does not act as a nursery habitat. Examples of 'site led' trout removals are two projects being undertaken by Otago Conservancy in cooperation with Fish & Game Otago.

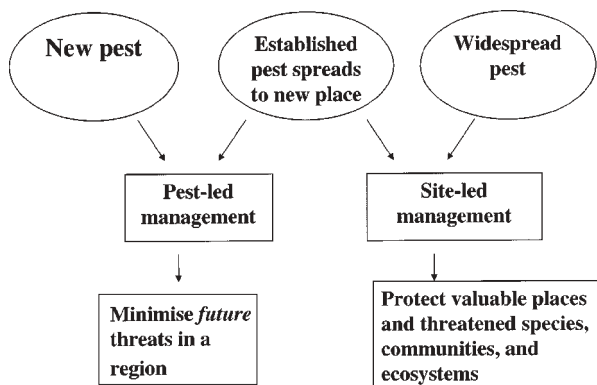


Figure 3. Summarised reasons for undertaking a pest-led or site-led approach to pest management. In a pest-led approach, the pest is targeted regardless of place to prevent further spread whereas in a site-based approach, the pest is managed to meet a place-based objective, e.g. protect a rare plant community (adapted from Owen 1998).

In Shepherd Stream, a water race has allowed brown trout to invade parts of the upper catchment that was previously isolated by a large waterfall, threatening a remnant Eldon's galaxiid (*Galaxias eldoni*) population (threatened species status—gradual decline, Hitchmough et al. 2002). The resident trout population is dominated by small fish with 90% < 150 cm in length (Fig. 4). The small nature of the stream (average width 1.5 m, average depth 0.3 m) ensures it is not suitable for sports fishing (Allibone & Neilson, unpubl. data), whereas removal of the trout will make available

c. 4.5 km of habitat for the Eldon's galaxiid. This new habitat will increase the available habitat by c. 450% and help buffer the population from natural fluctuations resulting from catastrophic floods, disturbances and drought years (Allibone pers. comm.)

The Orokonui Stream is a small system in coastal Otago that contains eight migratory native fish species and brown trout. A semi-permeable fish barrier across the lower reaches of the stream has been designed to provide passage for juvenile native fish, but prevent egress by sea run brown trout. Again this

TABLE 1. A SUBJECTIVE EVALUATION OF THE FEASIBILITY OF ERADICATING BROWN TROUT FROM NEW ZEALAND STREAMS, BASED ON STANDARD PEST ERADICATION CRITERIA (ADAPTED FROM OWEN 1978, BOMFORD & TILZEY 1997).

ERADICATION CRITERIA	SUBJECTIVE ASSESSMENT OF BROWN TROUT (NZ)
<i>All must be met before eradication should proceed</i>	
1. Rate of removal exceeds rate of increase (recruitment)	1. Yes, possible in small to medium sized waterways. Only if you can target all breeding fish, or can prevent access to suitable spawning habitat, and/or destroy all eggs in spawning habitat. Unlikely in rivers of any size - physically impossible, or techniques would fail criteria 5.
Links to other criteria. Eradication will only succeed if this is achieved.	
2. Low probability of reinvasion	2. No, except in small systems.
Requires assessment of vectors, source of founder populations, dispersal pathways. Linked to 5. - potential for people to reintroduce.	Limited ability to establish and maintain barriers to recolonisation in medium to large systems. Barrier may also exclude native fish. Too expensive on large systems.
3. Ability to target all individuals in a population	3. Yes, but only in some small to medium waterways.
Either directly or by preventing recruitment e.g. removing all individuals before they reach sexual maturity.	Technique dependent, difficulties with large, deep and fast flowing water bodies and springs, even using chemicals.
4. Populations can be monitored and targetted at low densities	4. Possibly
Target species needs to be able to be detected at low densities otherwise survivors may re-establish the infestation.	Limitations in large, fast flowing, deep, and or complex water bodies.
5. Suitable socio-political environment	5. No
Eradication objectives and methodology require local and national support.	Unlikely in anything but small waterways; public are likely to be adverse to large non-target deaths, and political and social unacceptability due to strong opposition from sport fishers.
6. Commitment /certainty	6. Yes, but only in small systems
Appropriate staff and resources need to be accurately identified and committed for the length of the programme.	Financial and staff resource preclude anything but small systems -costs of barrier maintenance, eradications, and compliance would be too large.

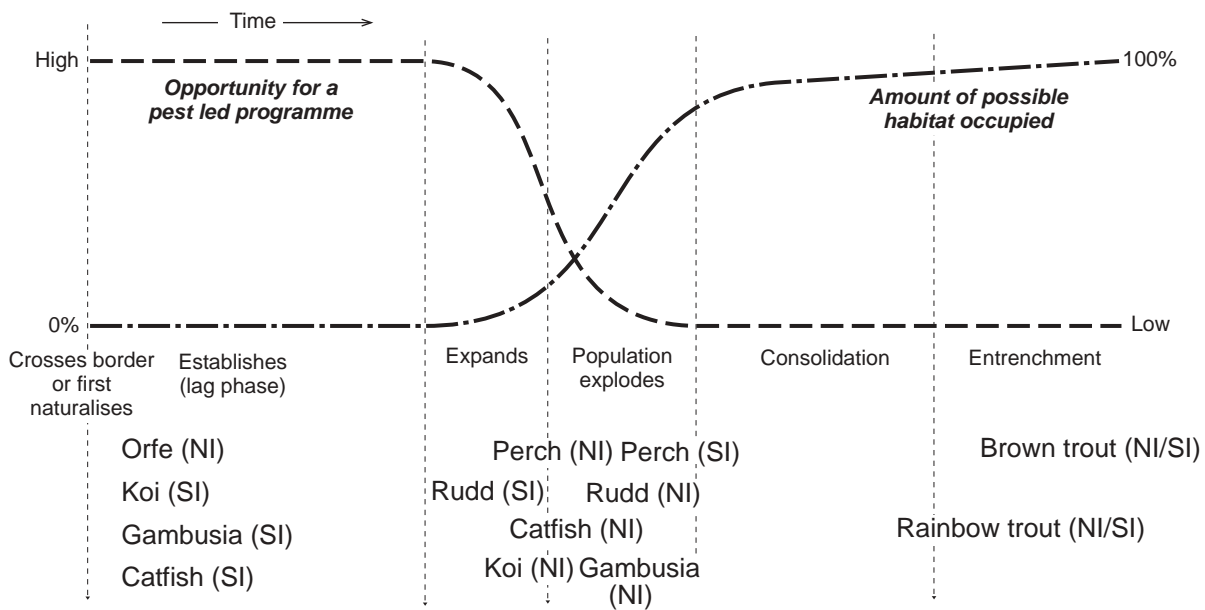


Figure 4. The relationship between the spread of a pest species, and the feasibility of a pest-led programme (adapted from Owen 1998). Approximate status of prominent pest species has been estimated based on current known distribution. (NI = North Island, SI = South Island.) Hence I consider that brown and rainbow trout populations have consolidated and/or are entrenched. Orfe (NI), koi, *Gambusia* and catfish (SI) are in the establishment phase, whereas perch and rudd (NI & SI) and North Island populations of koi, *Gambusia*, and catfish are arguably in various stages of population expansion.

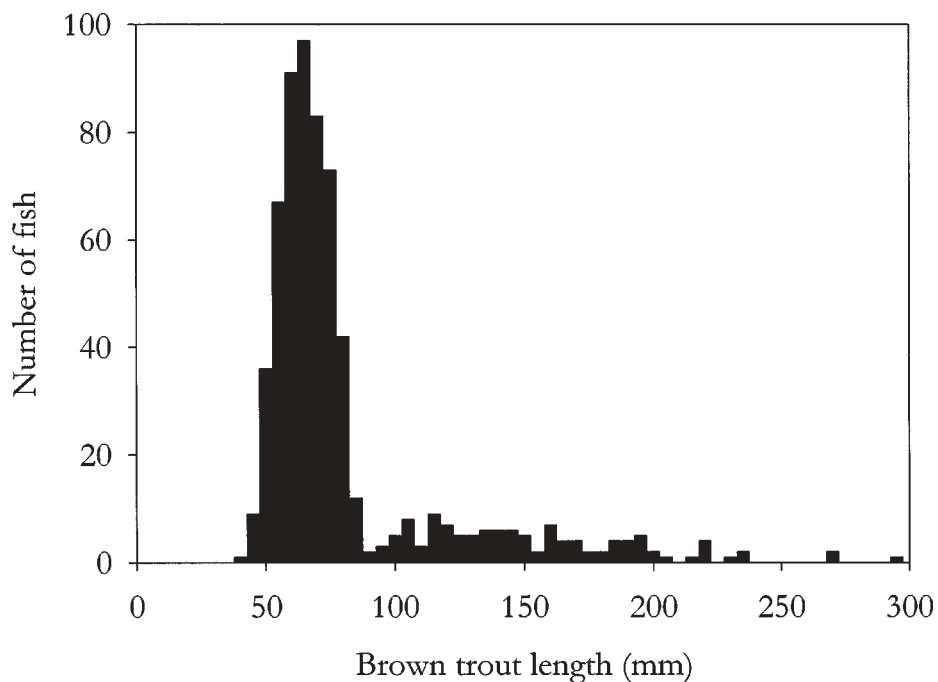
stream is a small 1-m-wide 3-km-long stream, of negligible fisheries value. The removal and permanent exclusion of trout should allow banded kokopu (*Galaxias fasciatus*), koaro (*G. brevipinnis*) and giant kokopu (*G. argenteus*) to maintain healthy self-sustaining populations and return the stream to its pre-introduction community. In addition, the site may also have potential as habitat for a threatened freshwater invertebrate *Austrodotea benhami*, an isopod apparently endemic to Otago Peninsula but whose long-term survival may be threatened by changes in land use (Chadderton et al. in press).

Many small streams do not contribute to the sports fisheries or generate revenue, but the continued presence of trout has an environmental cost (Allibone & McIntosh 1999). The management of these streams for conservation purposes has the potential for positive benefits for the threatened native species while also generating tremendous goodwill between agencies and interest groups with no cost to the fishery.

I demonstrated earlier that this is not the 'thin edge of the wedge', and that the wider community aspirations will have to be considered before such operations are contemplated. Where trout removals are proposed they should be part of an integrated site restoration project. I would expect that in most instances this means sites with high riparian values and minimal catchment modifications, to safeguard the asset being protected or restored.

DOC needs to identify and prioritise sites for protection. This is also a fundamental component of 'site led' pest management (Owen 1998) (Fig. 3). An objective site classification/prioritisation process based upon environmental distinctiveness (Overton & Leathwick 2001) and natural ecological character is being developed (Stephens et al. 2002). This process aims to objectively

Figure 5. Size frequency of brown trout removed from upper Shephard Stream.



identify and rank sites for protection and conservation management across the country. Site identification will also be driven by threatened species recovery plans that are presently being prepared for the large migratory galaxiids (giant, banded and shortjaw kokopu, and koaro), non-migratory galaxiids (16 species) and the five mudfish species. These plans will identify key populations for protection, and enable integrated catchment management of all threats, including pest species, to ensure their long term viability.

Invasive fish species are not just a conservation problem. Some noxious and sports fish species pose significant threats to ecosystem functioning (removal of aquatic plants, carbon sinks), water quality and turbidity and to the maintenance of other more valued introduced fish species like salmonids and water fowl (see reviews in Koehn et al. 2000; McDowall 1990; de Winton et al. present volume). Evidence presented by Barnes (present volume) and Dedual (2002) suggest the full repercussions for sport fisheries of the catfish introduction into Lake Taupo may not yet be fully realised. We can only speculate as to the implications of rudd or koi carp becoming established in Taupo or in the Rotorua lakes—two internationally recognised trout fisheries, and sites of significant value to Maori. Such introductions are likely to have far-reaching political implications. Therefore, in recognition that the continued spread of introduced fish is not just a conservation problem, we could adapt the original description of an invasive fish species to:

An invasive fish is any species that can significantly adversely affect the long-term survival of native species, the integrity or sustainability and functioning of natural communities or genetic variation within indigenous species; and it may **also** include any exotic species that threatens the integrity of populations of highly valued introduced species, or ecosystem services.

4. SOME FUTURE DIRECTIONS AND LESSONS FROM TERRESTRIAL PEST MANAGEMENT SYSTEMS

Finally I draw some analogies with terrestrial pest management from which I believe we can learn some valuable lessons. The recent pest fish incursions into the South Island (Shaw & Studholme 2001; Chadderton et al. present volume) and continued spread around the North Island has been greeted by some with a quiet resignation owing to the lack of tools and a seeming inability to prevent further illegal introductions. To steal a line from my terrestrial colleagues when summing up terrestrial conservation issues (Towns & Williams 1993), 'Soule noted that there are no hopeless cases, just expensive cases and people without hope'. This equally applies to freshwater conservation. Management of invasive fish is not a lost cause. In most instances, coarse fish species are still in the establishment phase (Fig. 4), where 'species led' pest management at either a regional or North/South Island scale can be contemplated. The priority must be containment and prevention of further spread to buy time while suitable tools are developed.

Waterways are effectively islands surrounded by a sea of land. Offshore island management principals would require that we establish an invasion contingency plan at important sites, and instigate effective waterway quarantine measures. This means blocking dispersal pathways and vectors, which in most cases are people. This is achievable but only with a unified and coordinated multi-agency approach can we hope to significantly slow dispersal rates. A multi-agency approach (including Fish & Game, DOC, MFish, MAF and local government) can make it very difficult for the illegal human vector to operate. Such an approach should encompass the inclusion of invasive fish species into regional pest management plans, and rigid compliance and enforcement by all fisheries agencies, including implementation of disincentive rules and regulations like the closures of sites to fishing where illegal introductions have occurred. A consistent public awareness and education programme should endeavour to make it socially unacceptable to introduce fish to any water body without the correct authority. Furthermore, by increasing awareness of the issues, thoughtless by-product or inadvertent introductions should decrease.

Concurrently, scientists have to start to develop or improve the management tools. Like island managers, we can start with small systems to fine-tune techniques before scaling up. Unlike Australia, New Zealand has an abundance of running water and potential small streams where we can trial new technologies and ideas.

Some of our priority invasive fish research needs include:

- Basic biological studies of species like rudd, koi carp and catfish to identify critical life stages or behaviours that make them vulnerable to detection, control or eradication (including territory and home range studies).
- A better understanding of the dynamics and vulnerabilities of founder pest populations to develop incursion responses. This includes behavioural studies of founder fish populations.

- Social research to identify the most effective ways to modify the behaviour of human vectors.
- Refining surveillance monitoring techniques and developing predictive models to better identify high probability invasion sites.
- Developing dispersal or containment barriers to safeguard pest-free systems from upstream invasions.
- Developing socially and environmentally acceptable eradication tools.

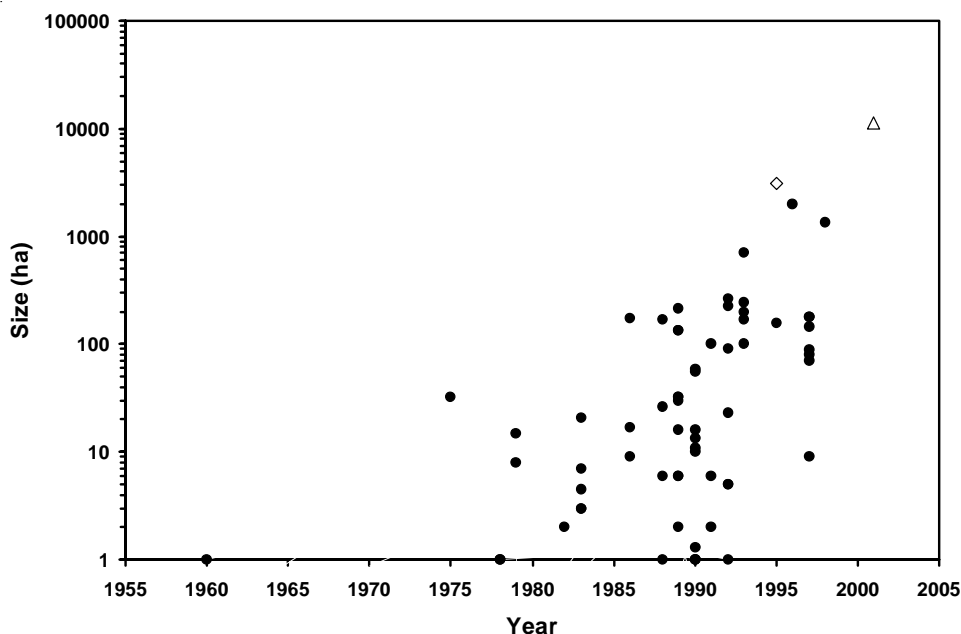
Impact studies are perhaps of lower importance, but these should focus upon demonstrating species-specific impacts where there are conflicting data, disagreement on the value and impacts of these fish, or a need to demonstrate management effectiveness or priority. Linked to this is the need for a better understanding of the impacts and dynamics of pest species assemblages.

For DOC, impact studies will be directed by the recovery needs of threatened native species and/or communities, where research that aims to identify threatening agents or processes will include the study of invasive species. In many instances these studies will occur within a research-by-management framework.

Returning to the island analogy: in 1962, ship rats invaded Big South Cape Island in Southern Stewart Island. Within 4 years, six endemic species were extinct (Atkinson 1989) and without rapid intervention a seventh, the South Island saddleback (*Philesturnus carunculatus carunculatus*), would also have been lost. It signalled a major low point in New Zealand conservation, and there was quiet resignation to the ultimate demise of our offshore islands' unique biota as a result of what seemed to be the inevitable invasion by rats. This view still pervaded conservation thinking 18 years later (Dingwall et al. 1978). But in the early 1980s, eradication tools began to be developed and following the eradication of rats off Breaksea Island (170 ha) in Fiordland (Taylor & Thomas 1993) there was a significant change in mindset. By the mid 1990s rat eradications had become a routine management technique (Towns & Williams 1993) with islands over 1000 ha being successfully cleared (Fig. 6), and in 2001 an attempt was made to eradicate Norway rats from 10 000-ha Campbell Island. All signs indicate that this has been successful (Peter McClelland, pers. comm.).

New Zealand freshwater biodiversity managers are facing an analogous situation to that confronted by terrestrial conservationists in the 1970s, i.e. there appears to be a slow but steady invasion of New Zealand's waterways by a suite of pests, and organisational inertia arising from perceptions that the continued spread of these species is inevitable. We need to follow the lead of those individuals who opposed the prevailing mindset in the 1970s. We have an advantage, for pest fish we do not have to work in isolation. There is active research and standard techniques in use in Australia and North America. In addition, unlike our international colleagues we are not hampered by state and federal boundaries. I believe that we can learn from international experience, and in collaboration with international researchers and managers and by adopting standard vertebrate and plant pest principles we can begin the restoration process and perhaps emulate the progress that our terrestrial pest managers have made.

Figure 6. The increasing size of islands from which rat eradications have successfully been undertaken as techniques were developed and improved over time. All dots represent islands in New Zealand. The diamond is Langara Island in Canada (that used New Zealand-developed techniques) and the triangle is Campbell Island where eradication was attempted in 2001, but final confirmation of success is not expected until the winter of 2003.



5. ACKNOWLEDGEMENTS

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