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FRAM: A fish risk assessment model for the importation and management of alien freshwater fish in New Zealand

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Executive Summary

Since European settlement, many deliberately introduced plants and animals have altered New Zealand's freshwater ecosystems. In particular, various introduced fish species have reduced populations of native fish, plants and water quality (McDowall 1984; 1987; Hanchet 1990; de Winton et al. 2003; Rowe 2007). It is crucial that New Zealand takes a proactive approach in preventing the introduction of any new pest fish species because the impacts can be severe and, in many places, may be irreversible. A key tool for the management of introduced fish is a method of predicting which introduced species can be expected to cause unacceptable environmental impacts. A comprehensive environmental impact assessment that includes tank, pond and field trials can provide this but is not always possible, feasible or desirable. A modelling approach is therefore required as a preliminary screening tool to identify the species posing little risk as against those requiring a more stringent EIA. This report provides such a modelling tool.

Overseas risk assessment methods were reviewed to identify the optimal structure and design for a New Zealand risk assessment model. Historically, risk assessments have been based on terrestrial plant and animal species and therefore focused on the potential 'invasiveness' of an alien species (i.e., its ability to establish and then spread both rapidly and widely). However, this approach is not useful for freshwater fish (Ricciardi & Cohen 2006). Freshwater fish are generally confined to river catchments and/or lakes and natural spread to another aquatic ecosystem is restricted mainly to diadromous species. Because of the restrictions on natural movement between freshwater ecosystems, most fish do not spread rapidly throughout a new host country. Hence 'invasiveness' is not as important as the potential to cause an environmental impact. We therefore designed the New Zealand risk assessment model to focus firstly on the risk of establishment in New Zealand, and secondly on the risk of causing an adverse environmental impact.

The questions developed for a freshwater fish risk assessment model for Australia (Bomford & Glover 2004) and for the United Kingdom (Copp et al. 2005) provided a comprehensive starting point for the development and customisation of a New Zealand Freshwater Fish Risk Assessment Model (FRAM). In general, the former addressed invasiveness and the latter impact assessment. The FRAM model is divided into two parts. Part A assesses the likelihood of the species establishing in the wild and Part B evaluates the size and potential severity of environmental impacts should an alien fish species become established in the wild. Most risk assessment models developed to date have been constructed from knowledge of the characteristics of known invasive fish species and few are subsequently ground-truthed using existing knowledge of the impacts of alien species in the host country. We therefore tested FRAM using the 21 alien fish species already present in New Zealand. The scores for these species were used to develop threshold scores for Part A and B as well as overall to assist in decision-making. The threshold scores were incorporated into a decision support system for assessing the overall risk of a new species either becoming a pest in New Zealand, or of an existing alien species spreading further and creating greater environmental problems.

1. Introduction

1.1 Background

The introduction and spread of alien (i.e., non-native) species is a major threat to global biodiversity and hence to ecological sustainability (Vitousek et al. 1997; Kolar & Lodge 2001; Sakai et al. 2001; Lee 2002; Dudgeon et al. 2006). In particular, studies of fish introductions to freshwater ecosystems in the Northern hemisphere have shown that some fish species can reduce native fish populations, degrade aquatic habitats, compromise gene pools, and increase the risk and spread of exotic diseases and parasites. The introduction of alien fishes is a major cause of biodiversity decline in freshwater ecosystems (Courtenay 1989; Courtenay & Stauffer 1990; Courtenay & Moyle 1992: Fuller et al. 1999; Canonico et al. 2005), and on a global basis, fish introductions are the prime cause of the extinction of many indigenous fish populations (Sala et al. 2000).

It is crucial that New Zealand takes a proactive approach in preventing the introduction and spread of alien fish species because the potential impacts can be severe. Species extinction is irreversible and cannot be justified by any benefits that stem from the importation of fish. Furthermore, few attempts have been made to eliminate pest fish in New Zealand (Rowe & Champion 1994; Dean 2003) and removal is expected to be difficult or impossible once alien species become established, especially in riverine ecosystems (Rowe 2003).

A key tool for the management of alien fish is a method of predicting which introduced species can be expected to cause unacceptable environmental impacts. A comprehensive environmental impact assessment that includes tank, pond and field trials can provide this but is not always possible, feasible or desirable. A modelling approach is therefore required as a preliminary screening tool to identify the species posing little risk as against those requiring a more stringent EIA. This report provides such a modelling tool for use by agencies with responsibility for the management of alien fish.

Three government agencies are responsible for problems arising from the introduction of alien freshwater fish in New Zealand. The Environmental Risk Management Authority (ERMA) makes decisions on the introduction of any new species not already present in New Zealand; Biosecurity New Zealand (MAFBNZ) deals with the quarantine of species and the control of pest species that are present and causing problems of national significance (including those responsible for disease transmission and health issues); the Department of Conservation (DOC) carries out management of alien species affecting native biodiversity and/or posing a risk to the habitat of native species. Regional Councils also have a responsibility for the control of alien fish species where they are a significant regional (if not national) pest. Decision-making by all these agencies requires an objective method for determining the risk of new or existing alien species harming biodiversity, the environment, amenity values, public health, or aquaculture. Such a tool would also be useful to fisheries management agencies contemplating the spread of such species to provide angling. Risk assessment methods have now been developed in a number of countries to assist in the management of alien fish species (e.g., Coates & Ulaiwi 1995; Kolar & Lodge 2002; Clunie et al. 2002; Marchetti et al. 2004; Kolar 2004; Van Eenennaam & Olin 2006; Webb 2006) and they have been shown to produce net bio-economic benefits to countries possessing them (Keller et al. 2007). A risk assessment model is therefore needed for New Zealand.

This report examines the risk assessment methods used by others for determining whether the introduction of an alien fish species could result in environmental damage and it presents a risk assessment model adapted to New Zealand conditions. It contributes to two of the three primary goals of the New Zealand Biosecurity Strategy (NZBS Goals 1 & 2) — "Preventing the entry and establishment of pests and unwanted organisms" and "early detection, identification and assessment of pests and unwanted organisms". The NZBS strategy identifies a clear need for more proactive assessment of emerging threats to enable identification of potential pests and pathways and implementation of measures to prevent their entry, spread and establishment. The production of a risk assessment protocol for freshwater fish helps achieve this.

This report is also relevant to the management of introduced fish that are already in New Zealand be they established in the wild or yet to be released. For example, the process of prioritising species for control or further research will benefit from a desk-top method for assessing the potential risk of establishment in the wild, or of impacts occurring should an alien species spread further.

1.2 The problem with introduced fish in New Zealand

Since European settlement, a number of deliberately introduced plants and animals have altered New Zealand's freshwater ecosystems (Champion et al. 2002; Closs et al. 2004). Although problems with introduced plants (e.g., gorse, blackberry) and animals (e.g., possums, deer, stoats) are highly publicised and well known, the effects of introduced aquatic plants and fish on freshwater ecosystems have received much less attention. Up to 50% of the aquatic plant species and 38% of freshwater fish species in our lakes and rivers are not native (Champion et al. 2002), and whereas some alien species have provided a benefit (e.g., trout), many have become unwanted pests.

Trout (*Salmo trutta* and *Oncorhynchus mykiss*) have done well as game fish since their introduction to New Zealand in the early 1900s (McDowall 2003). Brown trout are now widespread throughout the South Island and occur in the North Island (south of Auckland). Rainbow trout are less widespread but reach high densities in lakes and rivers of the central North Island where they form major freshwater fisheries. Although both species of trout are responsible for valuable fisheries in inland lakes and rivers throughout the country, this has not been without some environmental cost. In particular, a number of endemic galaxiid fish species have declined in rivers and lakes because of predation by trout (McDowall 2006). Furthermore, trout are now present in a number of lakes and streams where there is no angling but where the trout are affecting native species (Rowe & Graynoth 2002).

Although some introduced salmonids (e.g., brown and rainbow trout, chinook salmon) have created valuable fisheries that help offset environmental impacts, many other alien fish have few redeeming features. For example, koi carp (*Cyprinus carpio*) create turbidity problems in shallow lakes because of the high densities reached and their feeding habit of digging into lake beds and banks to feed on vegetation (Hanchet 1990). Hicks (2004) reported that densities of koi in parts of the Waikato catchment exceeded 2000 kg/ha and comprised about 90% of the fish biomass. Similarly, high densities of gambusia (*Gambusia affinis*) have resulted in the decline of native galaxiids in some North Island waters (Rowe 2003; Rowe et al. 2007), and rudd (*Scardinius erthythrophthalmus*) interfered with angling success, degrading a recreational fishery in a small Auckland lake (Rowe & Champion 1994). Because of such documented environmental impacts, gambusia and koi carp are now designated as ‘unwanted species’ in New Zealand. Along with catfish, rudd and perch, they are priorities for control in New Zealand (Chadderton et al. 2003).

But not all alien fish cause problems. Although goldfish have established widely, there is little evidence to suggest that this species has had an adverse impact on ecosystems, or other fish (Rowe & Graynoth 2002). Similarly, grass carp cannot breed within New Zealand and their distribution is tightly controlled by stocking permits. Although they can eradicate all weeds in lakes and so potentially cause an increase in turbidity, stocking is only permitted where removal of exotic weed species is required, so they do not pose a significant risk of environmental impact. Furthermore, some alien species are a problem in some locations but not in others. For example, perch (*Perca fluviatilus*) rudd and tench (*Tinca tinca*) can provide ‘coarse’ fishing in some waters (e.g., quarry pits, farm ponds) with little adverse environmental effect, but such species may cause problems in other waters (Rowe & Graynoth 2002; Dean et al. 2003).

It is clear from the New Zealand experience with alien fish that the nature and scale of adverse impacts can vary widely and between locations depending on both the alien species and its behaviour. Predicting the pest status and overall value of an alien fish species is therefore complex. It is the function of ERMA to weigh all the environmental and socio-economic factors (positive and negative) and this is not attempted here. The focus of this report is on the assessment of the risk of an environmental impact occurring should an alien fish species be introduced and become established in the wild in New Zealand.

2. Predicting invasiveness

Introduced species that spread widely and rapidly from the point of release and reach high densities are termed invasive species (Kolar & Lodge 2001). The impact an invasive species has on ecosystems and people distinguishes the most undesirable invasives. Kolar and Lodge (2001) described four steps in the invasion process for an introduced fish species. First the species needs a transport pathway to reach a new country or region. This may be deliberate (e.g., imported aquarium fish) or accidental (e.g., fish eggs on aquatic plants, or fry in boat bilge water). For the fish that survive transport, introduction to a natural stream or lake is the second step and often involves human intervention (e.g., deliberate or accidental stocking). At the third step, fish need to establish in the receiving environment and this requires suitable habitat for that species as well as an adequate release effort (propagule pressure) to allow breeding to occur. How favourable the habitat is and how the species interacts with the resident species (i.e., predators and prey) will determine whether the introduced fish survives in the ecosystem into which it has been released, whereas the breeding behaviour and life cycle of the species will determine whether it reproduces or not. The fourth step requires its spread to different catchments (or lakes), again mainly through human intervention. Invasion of a country by a new fish species may fail at any particular step, but is likely to be given many opportunities at each step. Nevertheless, Kolar and Lodge (2001) expected a progressively smaller proportion of species to reach sequential steps in the process, owing to a cumulative failure rate.

Information for predicting the establishment of an alien fish species in New Zealand (defined as the occurrence of a naturally breeding population in at least one natural waterbody) requires data on the risk of all four steps occurring. The initial release-effort (how many fish are released into the wild, where and how often) is an important determinant of whether a fish will successfully establish in the wild (Kolar & Lodge 2001; Bomford & Glover 2004), but useful data on this are not generally available. Some characteristics peculiar to certain species may predispose them to a higher release effort (e.g., popularity as a game fish, or use in biocontrol), but, apart from this generality, it is not possible to predict the initial release effort.

Predicting whether a fish will become established once released into a natural waterbody is a more useful approach. Two schools of thought have emerged on what determines the success of fish once released. The first is that the success of a species (assuming it survives introduction) will be determined by its competitive advantage over the fish already present (Vila-Gispert et al. 2005; Olden et al. 2006). If there are vacant niches, or the niches are occupied by less competitive species, then the introduced fish is expected to be invasive. Vacant niches may be natural where species diversity is low, or created where people have modified the environment (Olden et al. 2006). New Zealand's streams are considered more susceptible to the effects of introduced fish because of the relatively depauperate indigenous fish fauna (McDowall 1984) and the now extensively modified catchments. Niche gaps and competitive advantage no doubt play a part in how successful an introduced fish will be and its invasiveness. However, competitive advantage is hard to predict because it requires a detailed understanding of the ecology of the introduced species and that of the receiving environment (including the entire range of ecosystem types). It could be argued that predicting the density of a species (and therefore its invasiveness) within an ecosystem that it has never encountered is an impossible task.

The second school of thought, suggested by researchers such as Moyle and Light (1996), is that introduced fish can establish, regardless of native fish diversity, provided the habitat is suitable. Clearly, factors such as hot water temperatures, a lack of connectivity to the sea for diadromous species dependant on a marine phase for completion of their life cycle, or the absence of specific spawning/rearing habitats can prevent some species from becoming established in some waterbodies. However, such limitations aside, a new species can be expected to survive and breed in a new environment provided that; (1) it can tolerate the environmental conditions determined principally by the local climate and (2) that propagule pressure is high enough to allow the survival of enough fish to breed.

Determining the physical habitat requirements of an introduced species, and their likely match with habitats found in New Zealand is expected to be simpler and more reliable than predicting niche availability. Preventing importation of all alien species that are likely to establish in New Zealand exposes our aquatic ecosystems to much less risk than only stopping the importation of species that could produce an environmental impact. Climate matching, especially for the more vulnerable life history stages is therefore likely to prove a useful tool for predicting establishment.

The prediction of establishment risk is useful and feasible, but the prediction of invasiveness is more problematic. Invasiveness, or the rapid spread to and among many environments, is a poor indicator of potential environmental impacts for freshwater fish (Closs et al. 2004; Ricciardi & Cohen 2006). It provides a good indicator of potential problems related to alien plant and vertebrate species in terrestrial or marine environments because 'invasive' species are able to spread rapidly in such environments. In contrast, most freshwater fish populations are confined to catchments and or lakes and the lack of connectivity between such environments means that invasiveness is less relevant to 'pest' status than the impact they may have within the confines of a waterbody.

The first consideration for introducing a new species should be 'can the species become established in a New Zealand waterbody?' After screening out those species unlikely to establish, any attempt to predict pest status then needs to focus on the risk of the species causing an adverse impact in the waterbodies where it can become established. There might be cases where a species is permitted entry to New Zealand, despite a high risk of establishment, because it is very unlikely to create significant impacts (e.g., species such as goldfish, *Carassius auratus*). Conversely, there may be species of fish with such a high risk of potential impact on aquatic ecosystems that even a low risk of establishment is unacceptable (e.g., specialised piscivores such as the piranha). The two factors, risk of establishment and risk of impact, therefore need to be distinguished but considered together in any overall risk assessment model for freshwater fish

3. Overseas risk assessment tools and their applicability to New Zealand

Many screening methods have been developed to examine the traits and characteristics of alien fish that would predispose them to becoming pests outside their natural habitat (see review by Webb 2006). These methods are typically subjective and are often based on past experience with species that have become invasive elsewhere.

Two methods for the risk assessment of non-native freshwater fish, originating from the United Kingdom and Australia (Copp et al. 2005, Bomford & Glover 2004) showed more promise for application in New Zealand than others. For example, the Australian import risk analysis method for aquarium fish (Kahn et al. 1999) only deals with quarantine issues (i.e., unintentional release of diseases and parasites associated with fish). Similarly, Bomford (2003) developed a risk assessment procedure for vertebrates entering Australia, but this dealt primarily with terrestrial vertebrates not aquatic ones. The Australian weed risk-assessment method of Pheloung et al. (1999) has influenced other methods and it was adapted for plant pests entering New Zealand. However, the concepts developed specifically for freshwater fish by Bomford and Glover (2004) in Australia and Copp et al. (2005) in the United Kingdom are more relevant for New Zealand and provided a comprehensive and well-considered starting point for a New Zealand risk assessment method.

4. Adapting overseas methods for New Zealand

4.1 Conceptual changes

The U.K. method (Copp et al. 2005) focused on identifying species that are potentially invasive and that will create impacts, whereas the Australian method (Bomford & Glover 2004) focused primarily on whether an alien species can establish in the wild. The general approach taken by Bomford and Glover (2004) for Australia was adopted here, with the primary objective of identifying introduced fish that could potentially establish in New Zealand. Fish that become invasive (i.e., spread widely and reach high numbers) are a subset of those that have the potential to establish, and fish that will have major adverse impacts on the environment are a further subset. We therefore focus initially on establishment and secondarily on the risk of creating an environmental impact. This approach provides a wider safety-net that is less dependent on our ability to predict the degree of 'invasiveness'.

The Australian approach (Bomford & Glover 2004) was adopted as a basis for the New Zealand model, but with the questions adapted from the U.K. method (Copp et al. 2005). The questions used in the Australian method (Appendix 2) are more specialised and are based on an Australian climate model. New Zealand's climate is more uniform and has a narrower longitudinal range compared to Australia's (i.e., New Zealand lacks tropical and continental climate zones), so it is appropriate to use the more generalised U.K. questions on establishment in the New Zealand model.

The U.K. model (Appendix 3) considers the impacts of invasive species primarily in terms of the effects on primary natural resources (aquaculture, fisheries, etc.). For the New Zealand model we have shifted to a more ecosystem-based impact assessment. Potential impacts on aquaculture and fishing (commercial/recreational) are still addressed because the model considers the potential impacts of an introduction on fish and other biota. The New Zealand model also incorporates risks to biodiversity, to the habitats of other fauna or flora and to water quality, as alien fish have now been shown to cause a decline in all of these ecosystem attributes.

The U.K. method has two parts. The first is an initial screening tool to identify which species are potentially invasive and is called the Fish Invasiveness Screening Kit (or FISK). Species that are deemed to be either potentially invasive, or of unknown risk, trigger a second stage risk assessment that goes beyond a 'desk-top' assessment (IFRA – Invasive Fish Risk Assessment). A full Environment Risk Assessment (ERA) is required when there is uncertainty over a species and an ERA may require specific tank and pond trials to better identify species tolerances and interactions with other biota. Only the part one assessment (FISK) of the UK model was adapted for New Zealand.

4.2 Structure and questions

The New Zealand risk assessment model for freshwater fish (Appendix 1) is divided into two parts. Part A assesses the likelihood of a species establishing in New Zealand. Part B evaluates the risk of it causing an environmental impact, irrespective of its ability to establish. However, Part B also includes an assessment of its potential invasiveness in order to capture the geographical scale of any impact. In this context, invasiveness is an analogue for the potential spread of the species after its establishment and hence the potential magnitude of any impact.

The questions are based on the UK model but are customised to the New Zealand environment and are supplemented by additional questions more relevant to New Zealand. For example, New Zealand lacks both native herbivorous fish and pelagic piscivores. As these fish can affect the base of the food web and native fish species respectively, questions were added to the New Zealand risk assessment method in recognition of these niche gaps that potentially increase the risk of impacts. Similarly, planktivorous fish are known to exert top-down effects on water clarity in some locations, and are also included. Conversely, the impact of many introduced fish in New Zealand may be limited because they cannot access habitat above barriers such as culverts and waterfalls. Poor swimming ability and an inability to penetrate upriver is a factor limiting the potential spread and hence invasiveness of an alien species. Questions have therefore been added to account for this and other key factors that influence the risk of an environmental impact occurring.

Overall, the questions related to establishment of alien fish in New Zealand cover the history of establishment in other countries, the potential risk of being released into the wild (accidentally or deliberately) and the possibility of reproduction occurring in the wild in New Zealand. Questions related to the risk of an impact occurring cover the history of impacts in other countries, the reputation of congenitors or similar species, the scope for competition with native fish, the presence of natural controls, the likelihood of rapid reproduction, the probability of wide dispersal and any nuisance or health issues.

4.3 Scoring System

The scores for the various questions are cumulative such that a species with a high score is more likely to establish in New Zealand waterbodies and/or cause an adverse environmental impact. Accordingly, the scoring system is based on the following:

- questions are mostly scored as -1, 0 or +1 depending on whether the attribute reduces the likelihood or establishment or impact, has no effect, or increases it;

- higher or lower scores (ranging from -4 to +4) were given to attributes that, on their own, significantly increase/decrease the likelihood of species establishing &/or causing adverse environmental effects;

- scores for unknown responses default to the higher score where the consequences of increased risk are high, or default to a lower score where the consequences are low.

A draft risk assessment method was initially developed and this was tested on the 21 species of alien fish already present in New Zealand by three Department of Conservation fish specialists (N. Grainger, B. David, L. Chadderton). The scores for these species were compared to identify any obvious omissions based on the known impacts of these fish species in New Zealand. For example, scores for herbivorous fish were weighted upward because such species can have a major effect on the food base and fish habitat. The questions were extended, modified and clarified in response to reviews by both DoC and BSN.

The scores for all questions were then re-weighted to ensure a wider spread between the known benign and pest species. The scores for the alien fish species present in New Zealand for Part A, Part B and in total were then re-calculated are shown in Table 1 in descending order of overall risk to the environment.

Overall, the scores for establishment risk and for impact risk were well correlated ($r = 0.66$, $P < 0.01$). Species known to cause problems in some New Zealand waters (e.g., perch, carp, catfish) had high scores for the risk of both establishment and impact, whereas species causing no problems (e.g., guppies, swordtails and sailfin molly) had low scores for both establishment and impact. However, some exceptions to this general relationship were apparent (Figure 1). For example, grass carp had a relatively high risk of environmental impact but a low risk of establishment in New Zealand because this species does not breed in the wild in New Zealand. Similarly, goldfish, tench and brook char all had a high risk of establishment, but a relatively low risk of ecological impact.

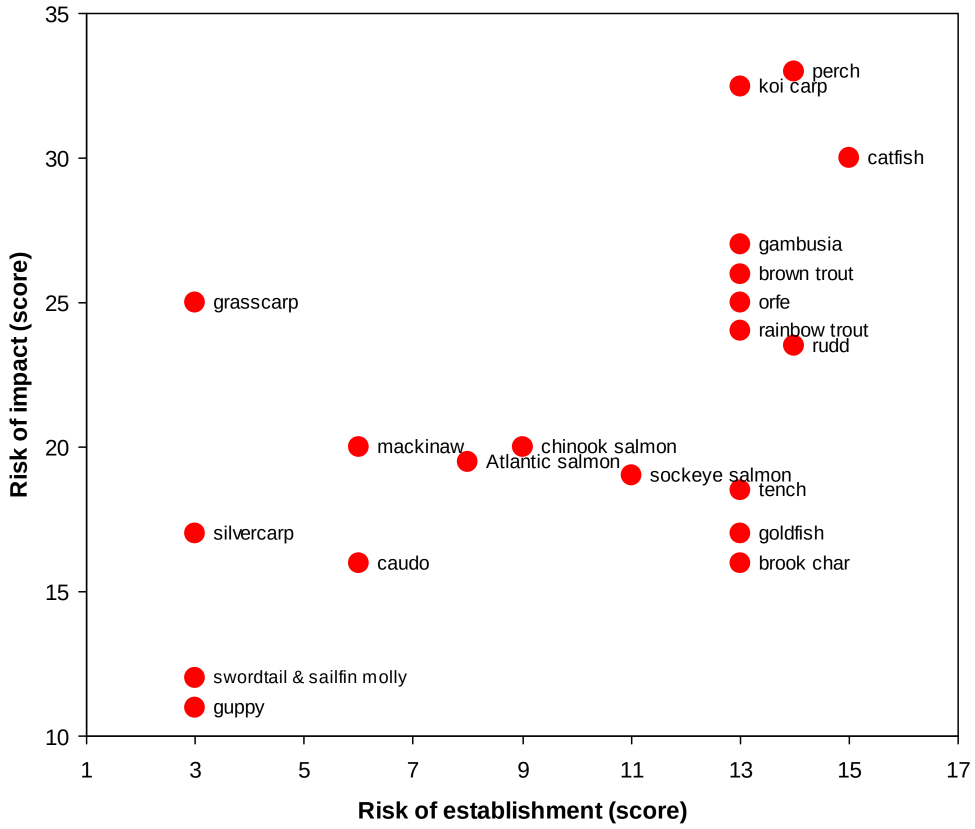

Figure 1: Relationship between the risk of establishment and the risk of causing an ecological impact for alien freshwater fish species in New Zealand.

The overall FRAM score (establishment + environmental risk) provides a measure of the potential ecological risk of introducing a new species to New Zealand. In general, the composite scores for the alien species already present in New Zealand provide a good fit to the documented impact these species are known to have had in this country. Perch and koi carp had the highest overall scores, followed by catfish, gambusia, trout, orfe and rudd (Table 1). Most species with overall scores of 37 or more have been associated with ecological impacts in New Zealand whereas those with scores of less than 32 have not (McDowall 1984, 2006; Rowe & Graynoth 2002; Closs et al. 2004; Rowe 2004, 2007; Rowe et al. 2008).

Table 1: Scores for the risk of establishment and of ecological impacts for alien fish species already present in the wild in New Zealand. ([1]Orfe are not known to cause impacts in New Zealand but this is because they are recorded from only one location and this has not been subjected to any study).

Species name	Common name	FRAM scores			Comment on species groups
		Establishment risk (max. 16)	Ecological impact risk (max. 61)	Overall ecological risk (max. 77)	
Perca fluviatilis	Perch	14	33	47	Species that have caused environmental impacts in NZ[1]
Cyprinus carpio	Koi carp	13	33	46	
Ameiurus nebulosus	Bullhead catfish	15	30	45	
Gambusia affinis	Gambusia	13	27	40	
Salmo trutta	Brown trout	13	26	39	
Leuciscus idus[1]	Orfe	13	25	38	
Oncorhynchus mykiss	Rainbow trout	13	24	37	
Scardinius erythrophthalmus	Rudd	14	23	37	
Tinca tinca	Tench	13	19	32	No impacts reported, but wide potential distribution
Carassius auratus	Goldfish	13	17	30	
Oncorhynchus nerka	Sockeye salmon	11	19	30	
Salvelinus fontinalis	Brook char	13	16	29	
Oncorhynchus tshawytscha	Chinook salmon	9	20	29	No impacts known because distribution restricted
Ctenopharyngodon idella	Grass carp	3	25	28	
Salmo salar	Atlantic salmon	8	20	28	
Salvelinus namaycush	Mackinaw	6	20	26	
Phallocerus caudimaculatus	Caudo	6	16	22	No impacts known and very restricted distribution
Hypophthalmichthys molitrix	Silver carp	3	17	20	
Xiphophorus helleri	Swordtail	3	12	15	
Poecilia latipinna	Sailfin molly	3	12	15	
Poecilia reticulata	Guppy	3	11	14	

The highest score for perch was not surprising. Although this species does not have the same global reputation for ecological impacts as carp, gambusia and trout, it has had a significant impact on native fish and crayfish in Australia (Rowe et al. 2008) and in New Zealand has been shown to affect indigenous eleotrid and galaxiid fish (Ludgate & Closs 2003; Rowe & Smith 2003) as well as facilitating algal blooms in eutrophic lakes (Smith & Lester 2007).

Species with overall scores of 26-32 formed two groups. Those with overall scores of 29-32 all had a relatively high risk of establishment but a lower risk of impact compared with those scoring between 26 and 29 (Table 1). The converse was true for this latter group. They all had lower establishment scores because of constraints on reproduction, but a higher risk to the environment. Species scoring 22 or less have even more constraints on reproduction and so have more restricted distributions.

The model provides a good fit to the known impacts of 21 alien fish species already present in New Zealand, including a range of species in the Salmonidae, Cyprinidae, Percidae, Poecilidae and Ictaluridae families. In this respect, it can be expected to be robust and work for other fish species in different families.

4.4 Threshold scores and decision-making

Threshold scores for triggering decisions on importation or management are required because there is no simple pass/fail score for either establishment or environmental risk. Part B assesses the risk of impact (how much of a problem a species could be if it did establish) and threshold values are set for this assessment depending on the risk of establishment (Part A). If the results of Part A show that the risk of establishment is low and the Part B assessment indicates a low risk of impact, then the species can be considered a safe import from an ecological point of view (although not necessarily a socio-economic one). Many tropical aquarium fish that only survive in warm waters are likely to fit into this category. Conversely, the importation of a species with a high risk of both establishment and impact would be prohibited or very tightly controlled so there is no risk of release into the wild. The proposed importation of large-mouthed bass (*Micropterus salmoides*) to New Zealand as a warm-water game fish provides a good example of a species with a high risk of both establishment and ecological impact (McDowall 1968).

If the risk of establishment is low and the risk of impact is high, then importation would need to be prohibited because a species can sometimes acclimatise outside its natural climate range. In particular, the increased likelihood of warmer water temperatures from climate change scenarios needs to be considered. Alternatively, conditions on importation would need to be imposed to ensure a full ERA is carried out. Even a small risk of establishment cannot be entertained if there is a high risk of impact as the future consequences could prove to be very expensive. A full ERA was carried out for the importation of grass carp into New Zealand and indicated that the risk of establishment was very low (Rowe & Schipper 1985).

If the risk of establishment is high and the risk of impact is low, then a full ERA is required to confirm the low risk of impact. The importation of channel catfish (for aquaculture) falls into this category. A more robust analysis of its potential to impact other fish eventually resulted in a ban on its importation (Glover 1989; Townsend 1991).

The FRAM model indicates that if the total score (for establishment plus impact risk) is 35 or more, the species has a high probability of both establishing and becoming a pest species in New Zealand. The importation of such a high risk species should therefore be prohibited unless it is confined to closed systems within secure facilities (e.g., aquariums, zoos, research laboratories). Where the total score is 25 or less then a species could theoretically be introduced with little fear of it becoming a pest species, but the final decision on this may depend on other socio-economic factors that may form part of the overall ERMA evaluation process. Species whose scores lie between these thresholds would require a fuller environmental risk assessment (ERA), potentially involving tank and pond trials under simulated New Zealand conditions to better determine tolerances and interactions with native biota.

Overriding decision 'triggers' are provided by responses to individual questions in both Part A and Part B. If the answer to Question 2.1 in Part A is 'no', then clearly the species will not establish in New Zealand, but this does not mean its release into the wild will not result in an impact and that its distribution does not need to be controlled through stocking permits. In Part B, Question 9 addresses taxonomic uncertainty and the risk associated with importation of alien parasites and pathogens. Both issues require a more stringent approach to quarantine procedures and therefore need to be flagged irrespective of their contribution to the risk of establishment and impact. All fish importations are expected to go through quarantine - the risk assessment procedure is not intended to replace this. However, a 'yes' response to Question 9.1 would trigger an alert, requiring consideration of more rigorous quarantine procedures to allow taxonomic clarification. Similarly, if a fish species has traits that may result in an increased risk to human health (e.g., intermediate host for parasites, or sharp spines causing injury, or capable of inflicting injury through biting) it needs to be flagged. A 'yes' response to Questions 9.2, 10.1, 10.2 and 10.3 would also raise flags.

The decision-support system and threshold levels for scores from the risk assessment protocol are shown in Figure 2. The model presented here is intended as an initial screening test for the potential of alien fish to establish and become invasive in New Zealand. More in-depth assessments (e.g., laboratory and pond-scale trials) can be used to provide a more reliable assessment of key components of the risk assessment, particularly for species close to the thresholds. However, the need for and scope of this is ultimately a decision for ERMA. Importers willing to make the extra investment could be given this option to demonstrate the acceptability of a new fish, but guidance or standards for such tests would need to be carefully formalised and audited.

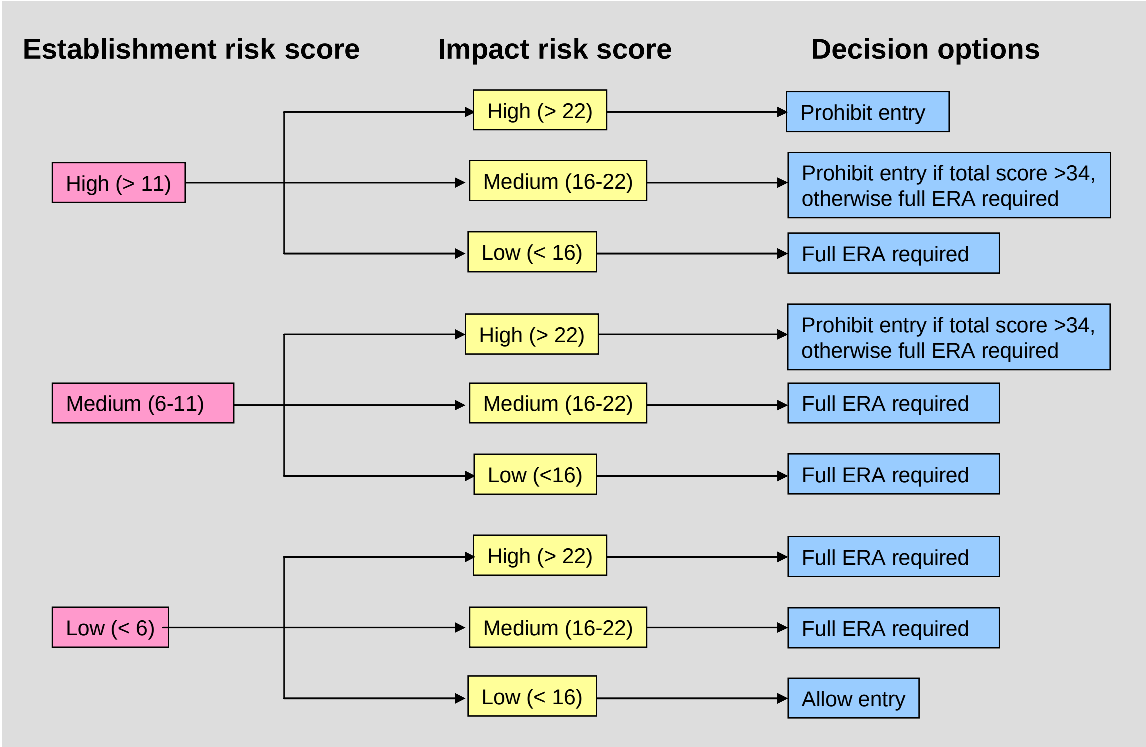

Figure 2: Decision support system for interpreting the scores produced by the New Zealand alien fish species risk-assessment (NB. A total score of 35 or more indicates that the potential risk of an environmental impact is unacceptably high, whereas a score of 20 or less indicates minimal or very restricted impacts).

5. Discussion

A model is provided for assessing the risk of an alien freshwater fish establishing and becoming a pest in New Zealand waters. The model's potential applications include preliminary border-screening of imported fish that are destined for the aquarium or ornamental pond trade, or for aquaculture and/or bio-control. The method also assists the management of alien fish species already established in the wild (e.g., by prioritising the risk of establishment beyond their current range, or the risk of environmental impact should they spread). Screening of fish already present in New Zealand but not present in the wild (e.g., some aquarium fish species), may also be undertaken to determine what threat these might pose and whether management (e.g., restricting sale and distribution) is required.

The scores produced by this model provide a good fit to the known impacts of existing alien fish species in New Zealand. However, it should be noted that many ecological processes, especially aquatic ones, are still not well understood and there is no coherent invasion theory that explains why some introduced species succeed and others do not. No ecological models are therefore fail-safe.

The assessment of habitat suitability in New Zealand was simplified to focus on the two main environmental factors affecting large-scale fish species distributions (e.g., temperature and salinity). This is because New Zealand offers a range of physical habitat conditions in terms of water depth, velocity, water types and hydrological disturbance regimes and suitable hydrological habitat for any given species will often be present somewhere in New Zealand. However, there is room for future development and refinement of this approach. Climate matching and habitat suitability offer many avenues for more robust and objective techniques. For example, the River Environment Classification network provides comprehensive information on the habitat provided by individual streams in New Zealand. This information was recently used to develop a risk map of potential habitat across New Zealand for the invasive algae *Didymosphenia geminata*. Such an approach could be used to assess habitat suitability of New Zealand rivers and streams for introduced fish. The availability of habitat preference data would be a limiting factor for many exotic species of fish, but climate matching still offers a promising avenue for research.

Predicting the potential impacts of introduced species is the focus of much international research. In time, this research is expected to support more advanced tools for managing biosecurity, including the effects of existing invasive species. This risk assessment model provides a tool that can be applied until better predictive methods become available. In this respect Bayesian probability theory, wherein the scores for the questions are replaced by a probability value and the overall risk of establishment and environmental impact is calculated using a Bayesian Belief Network approach (e.g., Pollino et al. 2006), may provide scope for improvement. However, selecting a probability value may prove to be more subjective than a score within a limited range.

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8. Appendix 1: New Zealand Freshwater Fish Risk Assessment Model (FRAM)

Part A - Establishment risk in New Zealand

		RESPONSE		
		NO	YES	UNSURE
1	**History of spread and climate match**			
1.1	Has the species a history of establishment outside its natural range?	0	1	1
1.2	Is it native to, or established in regions with similar climates to New Zealand?	0	1	1
1.3	Does it tolerate a wide climate range?	0	1	1
1.4	Is there a good climate match or overlap with waterways that are common in New Zealand?	0	Score 1 to 3 for a H/M/L match	3
2	**Reproduction possible in NZ**			
2.1	Can imported stocks produce viable gametes (e.g., sterile or triploid fish do not)?	Score -4 for overall assessment. Note that establishment risk is zero	1	1
2.2	Does the species have specific reproductive requirements to complete its life cycle (e.g., spawning habitat types or conditions) that are rare/absent in NZ?	1	if requirements rare score -1; if absent score -4	1
2.3	Is its reproductive habitat present within New Zealand?	0	1	1
2.4	Is its reproductive habitat widespread in New Zealand?	Score -3 if highly localised, -2 if rare, -1 if scarce	1	1
2.5	Does the species have a long (>10 years) life-span?	Score -1 if < 2 yr, otherwise 0	1	1
2.6	Does mating involve few (i.e., 1:1 mating) as against many fish?	0	1	1
3	**Vectors and propagule pressure**			
3.1	Is it likely to be readily introduced to natural waters. Probability will be higher for species used in some way (e.g., bait, aquaculture, biocontrol, angling, by-catch, ornamental)?	0	Score 1 to 3 depending on probability (H/M/L) of spread	0
3.2	Can large numbers of adult fish readily escape confinement or be easily transported to natural waterways because of either pelagic larvae or small size of adults?	0	1	1

Part B – Impact risk in New Zealand

		RESPONSE		
		NO	YES	UNSURE
4	**Reported impacts in other countries**			
4.1	Are there reported impacts on other fish species?	0	score 1 to 3 depending on severity (L/M/H) of impacts	2
4.2	Are there reported impacts on aquatic fauna other than fish?	0	score 1 to 3 depending on severity (L/M/H) of impacts	2
4.3	Are there reported impacts on aquatic plants?	0	score 1 to 3 depending on severity (L/M/H) of impacts	2
4.4	Are there reported impacts on water quality or fish habitats?	0	score -1 if positive effect, or 1 to 3 depending on severity (L/M/H) of negative impacts	2
5	**Feeding & Competition**			
5.1	Does the species eat aquatic plants (excluding planktonic algae and plant detritus)?	0	small part of diet = 1; voracious herbivore = 3	1
5.2	Does it eat or kill other fish?	0	small part of diet = 1; voracious piscivore= 3	1
5.3	Are adults planktivores (feeding on Daphnia)?	0	small part of diet = 1; major part = 3	2
5.4	Is it likely to compete with any native fish species for food or space?	0	score 1, 2, 3 for L/M/H overlap	2
5.5	Does its feeding or other behaviour reduce habitat quality for native species (e.g., change substrate, suppress macrophytes)?	0	score 1, 2, 3 for L/M/H overlap	2
5.6	Are its main natural predators present in New Zealand?	no major predators score =2; some major predators score =1	0	2

5.7	Does it have a reputation for aggressive, agonistic behaviour to other fish?	0	1	1
5.8	Is its feeding strategy widely adaptable (opportunistic omnivores are typically more adaptable)?	0	1	1
6	**Reproductive rate**			
6.1	Does it have a plastic reproductive strategy (e.g., low age-at-maturity, flexible spawning habitat, adaptable larval feeding strategy)?	0	1	1
6.2	Does it have the potential to hybridise with native species (or uses males of native species to activate eggs)?	0	1	0
6.3	Is the species able to change sex?	0	1	0
6.4	Is fecundity high (e.g., >10,000 eggs/kg, multiple spawnings per year)?	0	1	1
6.5	Does it mature at an age of 1+ or less?	0	If it matures at age 2 to 3 score 1, if older score 2	1
6.6	Does it produce live young (e.g., poeciliids) or exhibit parental care of eggs and/or young (e.g., mouth brooding, egg guarding)?	0	1	1
7	**Dispersal mechanisms**			
7.1	Are any life stages hardy and prone to unintentional release from boat bilge water, nets, trailers etc?	0	1 for low risk, 2 for high risk	1
7.2	Are life stages likely to be dispersed intentionally by people (e.g., potential game fish, biocontrol, baitfish)?	0	1 for low risk, 2 for high risk	-
7.3	Are eggs able to disperse widely (e.g., buoyant eggs or eggs attached to weeds, boats)?	0	1	1
7.4	Are larvae/juveniles able to disperse widely (e.g., pelagic larvae, juvenile migrations)?	0	1	1
7.5	Are juveniles or adults known to move large distances (e.g., spawning/feeding migrations, diadromous species, prone to displacement by floods)?	0	1	1
7.6	Are juveniles or adults able to climb or jump migration barriers (e.g., culverts and weirs)?	0	1	1
7.7	Are eggs likely to be dispersed by other animals (e.g., birds)?	0	1	1
7.8	Does the fish have a wide salinity tolerance (e.g., can it survive estuarine or marine conditions to reach other catchments)?	Score 0 for little tolerance. 1 for moderate tolerance, 2 for good tolerance	2	1

8	**Physical and chemical tolerances**			
8.1	Are any life stages able to survive extended periods (days) out of water?	0	survives in mud &/or wet ground score=1; survives in shaded &/or humid conditions score=2	0
8.2	Is the species tolerant of a wide range of water quality conditions (low oxygen, high temperature, low pH)?	0	1	1
8.3	Can the species occupy a wide range of habitat types (e.g., slow and fast water; deep and shallow water, weed/silt/rock substrates)?	0	1	0
8.4	Does it tolerate or benefit from environmental disturbance?	0	1	1
9	**Invasive relatives and special quarantine requirements**			
9.1	Does its taxonomic family or genus include any pest species, races, varieties, transgenics, or sub-species? (NB. if very difficult for quarantine staff to distinguish from target species then include all variants in evaluation)	0	1 (Flag the need for special quarantine conditions to allow taxonomic confirmation)	1
9.2	Does it have a reputation for hosting and/or transmission of parasites and pathogens that may affect other fish or humans?	0	1 (Flag the need for special quarantine conditions for disinfection)	1
10	**Undesirable traits**			
10.1	Is the species poisonous or does it pose other risks to human health (e.g., poison spines, toxic substances)?	0	1 (Flag the need for a more careful appraisal of potential harm to humans)	1
10.2	Is it likely to reduce people's use of waters (e.g., recreation, fishing, water abstraction)?	0	1 (Flag the need for a more careful appraisal of potential impacts)	1
10.3	Is it a host and/or vector for undesirable pests and pathogens affecting humans or other fish (and not already present)?	0	1 (Flag the need for special quarantine conditions for disinfection)	1

9. Appendix 2: FRAM scores for alien freshwater fish in New Zealand.

Question No.	perch	koi carp	catfish	gambusia	brown trout	orfe	rudd	rainbow trout	tench	sockeye salmon	goldfish	brook char	grass carp	chinook salmon	mackinaw	Atlantic salmon	caudo	silver carp	sword tail	sailfin molly	guppy
1.1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
1.2	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	0	0	0	0
1.3	1	1	1	0	0	1	1	0	1	0	1	0	1	0	0	0	0	1	0	0	0
1.4	3	2	3	3	3	3	3	3	2	3	3	3	1	3	2	3	1	1	1	1	1
2.1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
2.2	1	1	1	1	1	1	1	1	1	1	1	1	-4	-1	-1	-1	-1	-4	-1	-1	-1
2.3	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
2.4	1	1	1	1	1	1	1	1	1	1	1	1	-3	-1	-3	-1	-1	-3	-2	-2	-2
2.5	1	1	1	-1	0	1	1	0	1	0	1	1	1	0	1	0	0	1	-1	-1	-1
2.6	0	0	1	1	1	0	0	1	0	1	0	1	0	1	1	1	1	0	1	1	1
3.1	3	3	3	3	3	2	3	3	3	1	2	2	3	3	2	2	1	3	1	1	1
3.2	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	1	1	1	1	1
Establishment risk score	**14**	**13**	**15**	**13**	**13**	**13**	**14**	**13**	**13**	**11**	**13**	**13**	**3**	**9**	**6**	**8**	**6**	**3**	**3**	**3**	**3**
4.1	3	1	2	3	3	2	0	3	0	2	0	1	0	2	3	2	2	0	0	0	0
4.2	3	2	2	3	1	2	0	1	1	1	0	1	1	1	1	1	2	2	0	0	0
4.3	0	3	2	0	0	2	2	0	0	0	0	0	3	0	0	0	0	0	0	0	0

4.4	3	3	2	1	0	2	0	-1	1	0	1	0	2	0	0	0	1	-1	0	0	0
5.1	0	3	0	0	0	1	3	0	0	0	1	0	3	0	0	0	0	0	0	0	0
5.2	4	0	0	4	4	0	0	4	0	1	0	1	0	4	4	4	0	0	0	0	0
5.3	3	1	0	0	0	2	1	0	2	3	1	0	0	0	0	0	0	3	0	0	0
5.4	2	2	3	1	2	2	1	2	2	0	2	1	0	1	2	1	0	0	0	0	0
5.5	0	3	3	0	0	1	3	0	1	0	1	0	3	0	0	0	0	0	0	0	0
5.6	2	2	2	2	2	1	1	2	1	2	1	2	2	2	2	2	2	2	2	2	2
5.7	0	0	0	1	1	0	0	0	0	0	0	0	0	0	1	0	1	0	1	1	0
5.8	1	0	1	1	1	1	1	1	1	1	0	1	0	1	1	1	1	0	1	1	1
6.1	1	1	1	1	0	1	1	0	0	0	1	0	0	0	0	0	1	0	1	1	1
6.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6.3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6.4	0	1	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	1	0	0	0
6.5	2	2	2	0	2	2	2	2	2	2	2	2	2	2	2	2	1	2	1	1	1
6.6	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	1	1
7.1	0	1	2	2	0	1	1	0	1	0	1	0	0	0	0	0	1	0	1	1	1
7.2	2	1	1	2	2	1	2	2	2	1	1	1	2	1	1	1	0	2	1	1	1
7.3	1	1	0	0	0	1	1	0	1	0	1	0	1	0	0	0	0	1	0	0	0
7.4	0	0	0	0	1	0	0	1	0	1	0	1	1	1	0	1	0	1	0	0	0
7.5	0	1	0	0	1	0	0	1	0	1	0	1	1	1	0	1	0	1	0	0	0
7.6	0	0	0	0	1	0	0	1	0	1	0	0	0	1	1	1	0	0	0	0	0

7.7	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7.8	1	0	0	1	2	1	0	2	0	2	0	1	0	2	1	2	0	0	0	0	0
8.1	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8.2	1	1	1	1	0	1	1	0	1	0	1	0	1	0	0	0	1	1	1	1	1
8.3	0	0	0	0	1	0	0	1	0	1	0	1	1	1	1	1	0	1	0	0	0
8.4	1	1	1	1	0	0	1	0	1	0	1	0	1	0	0	0	1	1	1	1	1
9.1	0	1	0	1	1	0	0	1	0	0	1	1	0	0	0	0	1	0	1	1	1
9.2	1	1	0	0	0	1	1	0	1	0	1	0	0	0	0	0	0	0	0	0	0
10.1	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10.2	0	1	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10.3	1	0	0	0	1	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0
Impact risk score	**33**	**33**	**30**	**27**	**26**	**25**	**23**	**24**	**19**	**19**	**17**	**16**	**25**	**20**	**20**	**20**	**16**	**17**	**12**	**12**	**11**
Overall ecological risk score	**47**	**46**	**45**	**40**	**39**	**38**	**37**	**37**	**32**	**30**	**30**	**29**	**28**	**29**	**26**	**28**	**22**	**20**	**15**	**15**	**14**