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Cefas

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Contents

1. Introduction and rationale

In growing recognition during the 1980s and 1990s of the threat to inland water species posed by non-native species (e.g. Wheeler, 1991; Claudi and Leach, 1999; Ciruna *et al.*, 2004), the UK Government began to develop an overall environmental risk strategy (UK DoE, 1995) that distinguished risk analysis (hazard identification, hazard assessment) and risk management (in which risk communication was notably absent). The UK risk strategy was subsequently improved (UK Defra, 2002, 2003b) to encompass four elements: 1) Risk Identification, 2) Risk Assessment, 3) Risk Management and Communication (referred to as "Addressing Risks"); and 4) Risk Review and Reporting. At about the same time, the UK government brought in controls on the keeping and release of non-native fishes through Orders passed under the Import of Live Fish Act 1980 (ILFA) to supplement existing powers contained within the Wildlife and Countryside Act 1981. These measures, 'The Prohibition of Keeping or Release of Live Fish (Specified Species) Order 1998' and and 'The Prohibition of Keeping or Release of Live Fish (Specified Species) (Amendment) (England) Order, 2003', provided controls on species of fish considered to pose a risk to native species or ecosystems in England and Wales.

Risk assessment protocols were not in place in the UK to categorize non-native species according to their relative risk to the UK environment. And existing codes of practice (CoP) for responsible fisheries management (ICES, 1995), which the UK helped to develop, were designed primarily for intentional releases. However, the scope of ILFA legislation includes non-native species already in the country (i.e. it was intended to provide additional controls for those non-native species either here already or those most likely to get here). In absence of risk assessment protocols, the 'ILFA list' was drawn up based on the precautionary approach (IUCN, 1987; UK Defra, 2002; 2003a). The Convention on Biological Diversity (CBD, 2001) guidelines include a recommendation that risk assessment is used to justify actions taken against threats to biodiversity. Therefore, the UK government commissioned work in 2002 to develop protocols to guide the assessment of risks posed by non-native freshwater fishes (UK Defra, 2001).

Some qualitative and semi-quantitative protocols have already been developed for intentional fish introductions (e.g. Kohler and Stanley, 1984; Kahn, 1999) or both intentional and unintentional species introductions (e.g. US ANS Taskforce, 1996), including the largely marine-based CoPs for responsible fisheries management (ICES, 1995, 2004; Shine *et al.*, 2000) that form the basis of the FAO CoP (1995). A distinctly quantitative approach to hazard identification by Kolar and Lodge (2002) involves decision-tree analysis of ecological and biological characteristics of existing non-native species in a specific region to predict future invasive species from the same donor region. Some of these approaches deal primarily with the first element (hazard identification) of a risk strategy (e.g. Kolar and Lodge, 2002) and none of them combines the quantitative decision-making tools required under the World Trade Organisation Sanitary and Phytosanitary (SPS) Agreement (www.wto.org) and the qualitative decision-support systems espoused by the guidelines of international policy and principles on alien species (e.g. Convention on Biological Diversity, CoP6 Decision VI/23, 2002).

Within the European Union context of open trade, restrictions on the importation of non-native fishes would require an official recognised risk assessment standard. Under the SPS Agreement, only three such standard setting bodies are recognised: the Office International des Épizooties (OIE), the Codex Alimentarius Commission (human health), and the International Plant Protection Convention (IPPC) - interim commission. Indeed, non-native species risk assessment protocols are most advanced for plants and plant pests (e.g. Tucker and Richardson, 1995; Panetta *et al.*, 2001). However, plant and animal invasions share many similarities (Arthington and Mitchell, 1984), and consequently the standards developed by the European and Mediterranean Plant Protection Organisation (EPPO), under the IPPC, for plant pests have been suggested as applicable to other taxonomic groups (UK Defra, 2003a). Equally important, the EPPO plant pest standard (PK5/1-4; EPPO, 2000) provides a decision-making framework into which quantitative scientific assessments can be incorporated. Unlike the existing schemes developed for aquatic organisms, the EPPO protocols prompt the assessor to consider potential adverse economic and social impacts, in addition to the negative environmental impacts, of the organism being assessed. However, the initial hazard identification phase of the EPPO (2000) scheme relies entirely on subjective assessor assessment and thus would benefit from a more objective evaluation of invasive potential so as to aid in the decision of whether assessment of the target species should continue into a more comprehensive (and relatively expensive) phase or whether it ceases (and the species placed on a list for monitoring of any change in status).

The aim of the present discussion paper is to propose a conceptual risk assessment approach for freshwater fish species that addresses the first two elements (hazard

identification, hazard assessment) of the UK environmental risk strategy described above. In doing so, the present paper presents a few worked examples of assessments on species to facilitate discussion whilst validation of the proposed methodology (e.g. Daehler *et al.*, 2004) takes place.

2. Methodology

Implementation of the Hazard Identification and Hazard Assessment phases is a staged process, initiated by an initial screening tool to identify which species are potentially invasive. For species considered potentially invasive, a second phase, a more detailed risk assessment, is undertaken to determine the probability of introduction and to provide a detailed analysis of the risks of establishment or impact, neither of which is provided for in the Hazard Identification phase.

2.1 Hazard identification (screening)

During a review of existing hazard identification schemes, two approaches were deemed particularly suitable for the hazard identification stage: the Australian weed risk assessment (WRA) approach of Pheloung *et al.* (1999) and the Kolar and Lodge (2002) decision tree approach, known as 'fish profiling'. The Kolar and Lodge (2002) approach is highly numerical in nature, and its adaptation for fishes of Great Britain is the subject of an associated investigation (Gozlan, Welton and Copp, unpublished). The WRA approach of Pheloung *et al.* (1999) is semi-quantitative, with quantitative elements, and provides a simple spread-sheet based system for screening plants not present in Australia and New Zealand, and has been adapted for assessing invasive plants in Hawaii (Daehler *et al.*, 2004) and in the UK (P. Hulme, personal communication) as well as aquatic plants (R. Black, personal communication), Amphibia, marine invertebrates and fish in the UK (UK Defra, 2005).

The WRA approach is based on the biogeography and history of the species, the presence of "undesirable traits" and species biology and ecology, and relies on the generally accepted premise that weeds in other parts of the world have an increased chance of being weedy (i.e. invasive) in other areas with similar environmental conditions (Pheloung, 2001). The spread-sheet consists of a series of questions (responses: Yes/No/Don't Know) that are selected on the basis of expert evaluation of published literature on the species under evaluation. Each question is scored, generally on a scale of -1 to +1, to produce a total numerical score that is positively correlated with 'weediness' (Pheloung, 2001). In addition, each score is assigned to a category (agriculture, environmental, nuisance or combined), so that when the final score is calculated the sector most likely to be affected can be identified. The total score is then compared against a set of critical values that determine whether a species poses a high, low or uncertain risk of becoming invasive.

The WRA methodology has been used here to develop 'FISK', the Fish Invasiveness Screening Kit. Many of the original WRA questions were found to be conceptually relevant to fish and required little or no modification. Others were modified to reflect trends or characteristics of importance to freshwater fishes and their potential invasiveness (see Bruton, 1986; Baltz and Moyle, 1993; Moyle and Light, 1996; Jackson *et al.*, 2001; Kolar and Lodge, 2002). The scoring system was retained virtually the same, with a few, slight modifications. As an initial evaluation of the applicability of FISK, including whether use of the original scoring system seemed appropriate, trial assessments were run on a few non-native freshwater fish species from North America, Europe and Asia. Trial species were chosen that:

1) had already been introduced to, and were successfully established in, the UK – to determine whether successful invaders would attract high scores and be classed as invasive;
2) are potential invaders that have yet to be recorded in the UK – to determine whether these species would attract high scores and be classed as invasive;
3) are considered unlikely to establish (e.g. restricted native range, no known successful introductions outside their native range) – to determine whether these species would attract low scores and be classed as non-invasive; and
4) had been introduced into the UK but had either failed to establish self-sustaining populations or did so for only a limited period before the species died out naturally.

2.2 Hazard assessment

Following initial screening, a hazard assessment phase, referred to as the Invasive Fish Risk Assessment (IFRA), was developed. Concurrent with recommendations of the UK non-native species review (UK Defra, 2003a), the EPPO plant pest standard (PK5/1-4; EPPO, 2000) was adapted for assessing non-native freshwater fishes using specialist knowledge of the environmental biology of fishes in consultation with a variety of environmental risk assessment guidelines (ICGPSIA, 1994; US ANS Task Force, 1996; US EPA, 1998; IUCN, 2000; USDA, 2002; UK Defra, 2003a, 2003b; Bomford, 2003). Three sections are proposed within IFRA: Introduction, Establishment and Impact. As in the initial screening phase (FISK), the hazard assessment phase (IFRA) assumes that past invasiveness history and environmental similarity are important for determining the level of risk posed by a species (Ricciardi, 2003).

In carrying out the FISK assessments (nine in total) and the lone IFRA trial, informed responses were made after reviewing the available published literature, which included peer-reviewed journals, books, so-called 'grey' sources (reports, bibliographic reviews, popular science magazines and newspapers), internet sources (using search engines and on-line databases such as available at 'www.fishbase.org' and 'www.fao.org'), and, for unpublished information, through consultation with scientific colleagues (an element of 'risk communication'), including those of major non-governmental organisations. In particular, the trial IFRA assessment of topmouth gudgeon *Pseudorasbora parva* benefited from information on potential impacts provided by J. Mumford of Imperial College, London (personal communication) for the economic impact assessment and from E. Peeler of Cefas-Weymouth (personal communication) for the fish disease assessment. Consultation with the general public was not incorporated due to resource limitations. The assessor is expected to provide a brief rationale (with references) with each response.

3. Results and discussion

3.1 Hazard identification (Phase I) – Fish Invasiveness Screening Kit (FISK)

The questions included in Phase I (hazard identification or screening) cover a wide range of attributes selected to accurately screen for species with invasiveness potential in freshwater fisheries (including aquaculture) and the natural environment (Table 1). FISK is divided into two sections: biogeography and history, biology and ecology.

3.1.1 FISK Part A: Biogeography and History

As in WRA, the Biogeography/History section of FISK includes questions under three categories: domestication, climate and distribution, and invasive history.

Domestication/cultivation (Section A1, Table 1):
Domestication is considered to be important because of the potential for enhanced fitness (in terms of growth rate, mating success and/or fecundity) in domesticated strains (including transgenic strains) over wild strains (e.g. Muir and Howard, 1999) and for the importance of domestication in determining 'prevalence'. Unlike plants, in which domestication has generally been found to reduce 'weediness', domestication of freshwater fishes has been found to increase invasiveness, e.g. common carp *Cyprinus carpio*, goldfish *Carassius auratus*, sunbleak *Leucaspius delineatus*, topmouth gudgeon (e.g. Balon, 1995; Gozlan *et al.*, 2002). So, the WRA scores of Q 1.01 (no = 0, yes = -3) were modified to reflect the greater invasiveness of domesticated fish species (Table 1). Like in WRA, fish species with a history of naturalisation outside their native range (Q 1.02) are more likely to be invasive, so the WRA score is retained. However, in Q 1.03, the absence of invasive races/varieties or subspecies in fish does not preclude a species from being invasive (see Ricciardi, 2003), such as has been attributed to plants (Pheloung *et al.*, 1999). So the WRA score (n = –1) was modified slightly in FISK (Table 1).

Climate and Distribution (Section A2, Table 1):
The similarity of climatic conditions between the source and recipient areas is assumed to influence the probability of successful establishment (i.e. reproduction) and increase the likelihood of adverse impact (Reichard, 2001). Ideally, climate matching should be undertaken using a computer analysis tool such as CLIMEX (Sutherst *et al.*, 1999) or GARP (Payne and Stockwell 2004), which are dynamic simulation models developed to predict potential

geographical distributions of species by using climatic parameters inferred from an observed distribution. These models use terrestrially derived temperature data, which, in terms of freshwater fish species, may be useful only in identifying potential distribution at a very broad scale. The climate-matching concept, and all questions in this section (Q 2.01 to Q 2.05) remain virtually identical to WRA, but with a few score modifications. The scoring sub-routine for the climate matching exercise is:

Climate match output score:	0	1	2	Quality level:
Question: Score explanation:				
2.01 High risk assumed due to low quality data		2.0	2.0	2.0	qlow
2.02 Moderately rising risk as quality of data improves		1.0	1.5	2.0	qmed
2.03 Steeply rising risk as quality of data improves		0.5	1.0	2.0	qhi

In the absence of a climate-matching exercise, a high default score is attributed to ensure that a conservative (precautionary) approach is taken.

Regarding the species' history of repeated introductions outside its natural range (Q 2.05), the WRA 'no' response (no = 0) has been re-scored (Table 1) because a low number of introductions in aquatic species may result in a limited 'introduced' distribution and thus decrease the probability of invasive dispersal.

Invasive Elsewhere (Section A3, Table 1):
Invasive history (measured as history of introduction, naturalisation, and impact) of a species or its congeners is a good predictor of invasiveness potential (e.g. Ruesink *et al.*, 1995; Reichard, 2001). This is supported, with regards freshwater fishes, by Kolar and Lodge (2002) who found that a history of invasiveness was characteristic of successfully establishing species in the Great Lakes of America. This was also found to be a principal factor in the establishment success of fishes introduced to the UK (Gozlan, Welton and Copp, unpublished). The questions relating to impact history are weighted according to the climatic similarity scores and the quality of climate matching data used. A heavier weight is accorded to the questions relating to impact on commercial sectors (fisheries or aquaculture), on wild stocks and on angling amenity values than on the ornamental sector because of the closer relation of these

sectors to the natural environment (scoring routine for Table 1):

Input response:	?	N	Y
Question: Score explanation and weighted score:			
3.01 Reflects importance of establishment history outside native range	-	1	2
3.02 Impacts at population level attract higher score	-	0	2
3.03 Impacts to commercial sector attract highest score	-	0	4
3.04 Impacts at ecosystem level attract highest score	-	0	4
3.05 Status as member of invasive genus adds to risk	-	0	2

3.1.2 FISK Part B: Biology and Ecology

This section aims to assess the primary ways by which a species may be invasive and have an impact by considering the various biological and ecological characteristics that enable a species to reproduce, spread and persist (Pheloung et al., 1999).

Undesirable Traits (Section B4, Table 1):

Freshwater fish introductions may result in impacts as a result of one or many undesirable characteristics, including: competition (e.g. Janssen and Jude, 2001), habitat alteration (Crivelli, 1983), parasitism (Trombitskiy and Kakhovskiy, 1987), predation (Simon and Townsend, 2002; Pusey et al., 2003), host of pests or parasites (Kennedy, 1993; Gozlan et al., 2005), hybridisation (Wheeler, 2000), alteration of habitat quality and/or ecosystem function (Moyle et al., 1986; Arthington, 1991; Simon and Townsend, 2002). Also considered are characteristics related to toxicity or risks to human health, the potential for absence of natural predators in the receiving environment, and the ultimate size of the species. This is particularly relevant in countries such as the UK in which novel fish species (e.g. sturgeons, cyprinids) of large ultimate size are increasingly common in the ornamental (especially garden pond) trade. As these fish eventually out-grow their aquaria or garden pond, they are more likely to be deliberately released into the wild than small species (Copp et al., 2005b; Duggan et al., 2005). The new fish questions in this section are unrelated to the original 'weed' questions, but WRA scores were retained for all questions except Q 4.04 and Q 4.12 (Table 1); Q 4.04 — the WRA response (no = -1) was reduced

because in fish the susceptibility to predation does not preclude invasiveness; Q 4.12 — the scores were inversed to reflect the greater risk of establishment in fish species that are not constrained by minimum population size.

Feeding guild (Section B5, Table 1):

This group of questions replaces the WRA 'Plant type' section. Fishes are most commonly classed by trophic guild, though ecological and reproductive guilds are also used, depending upon the application (Schiemer and Waidbacher, 1992). Many species of fish vary their diets as a consequence of ontogeny or opportunity (Jackson et al., 2001), and those that are predatory or omnivorous at some stage of their life cycle are more likely to be successful invaders (Ricciardi and Rasmussen, 1998). In WRA, aquatic plants were allocated a disproportionately high score relative to other plant types because of their potential to choke waterways and starve the system of light, oxygen and nutrients. In fishes, an equivalent modification to ecosystem function in UK inland waters is most likely to be observed with introduced piscivorous (Q 5.01) and benthivorous (Q 5.04) species (e.g. pikeperch Sander lucioperca, common carp, respectively). The disproportionately higher score used in WRA for 'aquatic plants' (yes = 5) is not warranted in FISK. Documented evidence of impacts in fishes is mainly associated with piscivorous and benthivorous fishes, but this remains equivocal.

Reproduction (Section B6, Table 1):

Life history characteristics will directly influence invasive ability, which is assumed to be a combination of overall life history style (fecundity, spawning requirements, gamete viability, reproductive strategy) and phenotypic plasticity (Bruton, 1986). Of particular importance is the dependence of a species on other species or on specific habitat features to complete its life cycle. For example, the bitterling Rhodeus sericeus cannot reproduce unless a suitable mussel is present in which to incubate its eggs, and these molluscs are generally found only in cleaner waters. Similarly, grass carp Ctenopharyngodon idella has highly specific water flow requirements for natural spawning to occur. Scoring in this section remained unchanged from WRA except for Q 6.04, hermaphroditism, which in contrast to plants is relatively rare in vertebrates (Ho, 2004) but nonetheless increasingly reported in fishes; thus, the WRA score (no = -1) was elevated to zero (Table 1). Minimum generation time (in years) remained the same as for plants, and the input value is converted to a score as follows: 1 year = 1; 2-3 years = 0; ≥4 years = -1.

Table 1. Fish Invasiveness Screening Kit (FISK) protocol for hazard identification in non-native freshwater fishes (adapted, with permission, from Pheloung *et al.* 1999), with responses given for topmouth gudgeon *Pseudorasbora parva* as an example (N.E. = numerical equivalent of response; ? = unanswered question, normally due to lack of information). The scoring sub-routines for 'climate matching' and 'invasive elsewhere' and 'generation time' are described in Section 3.1.1. Scoring categories (in parenthesis) are: A = aquaculture, E = environmental, N = nuisance, C = combined. TRUE confirms that the minimum number of questions has been answered.

species name: *Pseudorasbora parva* common name: topmouth gudgeon Assessor: G.H. Copp

Risk query		Response	N.E.	Score ?	Response N	Y
A. Biogeography/historical						
1	*Domestication/cultivation*					
1.01 (C)	Is the species highly domesticated or cultivated for commercial, angling or ornamental purposes?	y	2	2	0	2[†]
1.02 (C)	Has the species become naturalised where introduced?	y	1	1	-1	1
1.03 (C)	Does the species have invasive races/varieties/sub-species?	y	1	1	0[†]	1
2	*Climate and Distribution* (uses score weighting, see Section 3.1.1)					
2.01 (C)	Is species reproductive tolerance suited to climates in Great Britain (0-low, 1-intermed, 2-high)	2	2			
2.02 (C)	Quality of climate match data (0-low; 1-intermediate; 2-high)	0	low			
2.03 (C)	Broad climate suitability (environmental versatility)	y	1	1	0	1
2.04 (C)	Native or naturalised in regions with equable climates	y	1	1	0	1
2.05 (C)	Does the species have a history of introductions outside its natural range?	y	2		-1	2
3	*Invasive Elsewhere* (interacts with 2.01 to give a weighted score, see Section 3.1.1)					
3.01 (C)	Has the species naturalised (established viable populations) beyond its native range?	y	1	2	-1	1
3.02 (N)	In its naturalised range are there impacts to wild stocks of angling or commercial species?	y	1	2	0	1
3.03 (A)	In its naturalised range are there impacts to aquacultural, aquarium or ornamental species?	?		0	0	2
3.04 (E)	In its naturalised range are there impacts to rivers, lakes or amenity values?	y	2	4	0	2
3.05 (C)	Does the species have invasive congeners?	?		0	0	1
B. Biology/Ecology						
4	*Undesirable (or persistence) traits*					
4.01 (C)	Is the species poisonous, or poses other risks to human health?	n	0	0	0	1
4.02 (C)	Does the species out-compete with native species?	?			0	1
4.03 (C)	Is the species parasitic of other species?	y	1	1	0	1
4.04 (A)	Is the species unpalatable to, or lacking, natural predators?	n	0	0	0	1
4.05 (C)	Does species prey on a native species (e.g. previously subjected to low (or no) predation) ?	n	0	0	0	1
4.06 (C)	Host and/or vector for recognised pests and pathogens, especially non-native	y	1	1	0	1
4.07 (N)	Does the species achieve a large ultimate body size (i.e. > 10 cm FL) (more likely to be abandoned) ?	n	0	0	0	1
4.08 (E)	Has a wide salinity tolerance or is euryhaline at some stage of its life cycle	?			0	1
4.09 (E)	Is desiccation tolerant at some stage of its life cycle?	?			0	1
4.10 (E)	Is tolerant of a range of water velocity conditions (e.g. versatile in habitat use)	y	1	1	0	1
4.11 (E)	Feeding or other behaviours reduce habitat quality for native species?	y	1	1	0	1
4.12 (C)	Does the species require minimum population size to maintain a viable population?	?			1[†]	0[†]

Table 1. continued. Fish Invasiveness Screening Kit (FISK) protocol for hazard identification in non-native freshwater fishes (adapted, with permission, from Pheloung *et al.* 1999), with responses given for topmouth gudgeon *Pseudorasbora parva* as an example (N.E. = numerical equivalent of response; ? = unanswered question, normally due to lack of information). The scoring sub-routines for 'climate matching' and 'invasive elsewhere' and 'generation time' are described in Section 3.1.1. Scoring categories (in parenthesis) are: A = aquaculture, E = environmental, N = nuisance, C = combined. TRUE confirms that the minimum number of questions has been answered.

Risk query		Response	N.E.	Score	?	Response N	Response Y
5	*Feeding guild*						
5.01 (E)	Piscivorous or voracious predator (e.g. of native species not adapted to a top predator)	n	0	0		0	2
5.02 (C)	Omnivorous	y	1	1		0	1
5.03 (C)	Planktivorous	y	1	1		0	1
5.04 (C)	Benthivorous	y	2	2		0	2
6	*Reproduction*						
6.01 (C)	Exhibits parental care of eggs and/or young and/or known to reduce age-at-maturity in response to environment	y	1	1		0	1
6.02 (C)	Produces viable gametes	y	1	1		-1	1
6.03 (A)	Hybridizes naturally with native species (or uses males of native species to activate eggs) ?	y	1	1		-1	1
6.04 (C)	Hermaphroditic	?				0	1
6.05 (C)	Dependent on presence of another species (or specific habitat features) to complete life cycle	n	0	0		0	-1
6.06 (A)	Highly fecund (>10,000 eggs/kg), iteropatric or extended spawning season	y	1	1		-1	1
6.07 (C)	Minimum generation time	1	1	1			
7	*Dispersal mechanisms*						
7.01 (A)	Life stages likely to be dispersed unintentionally	y	1	1		-1	1
7.02 (C)	Life stages likely to be dispersed intentionally by humans (and suitable habitats abundant nearby)	y	1	1		-1	1
7.03 (A)	Life stages likely to be dispersed as a contaminant of commodities	y	1	1		-1	1
7.04 (C)	Natural dispersal occurs as a function of dispersal of eggs	y	1	1		0[†]	1
7.05 (E)	Natural dispersal occurs as a function of dispersal of larvae (along linear and/or 'stepping stone' habitats)	y	1	1		0[†]	1
7.06 (E)	Juveniles or adults are known to migrate (spawning, smolting, feeding)	y	1	1		0[†]	1
7.07 (C)	Eggs dispersed by other animals (externally) ?	?				0[†]	1
7.08 (C)	Density dependent dispersal	y	1	1		0[†]	1
8	*Tolerance attributes*						
8.01 (C)	Any life stages likely to survive out of water transport?	y	1	1		-1	1
8.02 (C)	Tolerates a wide range of water quality conditions, in particular oxygen depletion and high temperature	y	1	1		-1	1
8.03 (A)	Susceptible to piscicides	?				1	-1
8.04 (A)	Tolerates or benefits from environmental disturbance	y	1	1		-1	1
8.05 (C)	Effective natural enemies present in Great Britain	y	-1	-1		1	-1

	Outcome:	Reject		
	Score:	36	Tolerance settings	
Statistical	Biogeography	14	Accept = -2[†]	
summary	Score partition: Undesirable atributes	4	Evaluate = 0	
of scoring	Biology/ecology	18	Reject = 6	
	Biogeography	10	Total	minimum
	Questions answered: Undesirable attributes	8	10	2
	Biology/ecology	21	8	2
	Total	39	21	6
	Aquacultural/Fisheries	26	39	10
	Sector affected: Environmental	29		
	Nusiance	2		

[†] indicates change from WRA (Pheloung *et al.* 1999) scores (see text).

Dispersal mechanisms (Section B7):

The ability of a species to disperse is a primary determinant of invasive ability, and most risk assessment approaches predict that species commensal with human activity will pose the greatest risk (e.g. Ruesink *et al.*, 1995; Ricciardi and Rasmussen, 1998; Kolar and Lodge, 2002). Natural dispersal ability will however also influence how quickly a species can spread and the subsequent magnitude of impact – although this will be influenced by presence of geographic barriers (see Copp *et al.*, 2005a). Scoring in this section remained unchanged for questions 7.01 to 7.03 (Table 1), whereas the WRA scores (no = -1) for questions 7.04 to 7.08 were elevated (from -1 to 0) because the absence of these attributes in fishes does not imply a lesser invasiveness risk.

Tolerance attributes (Section B8, Table 1):

Species with high environmental tolerances are more likely to be good invaders, with the most important environmental determinants for fish being temperature, salinity, oxygen, water velocity, and water quality or environmental disturbance (e.g. Moyle and Light, 1996; Jackson *et al.*, 2001; Kolar and Lodge, 2002). Scoring of these attributes in FISK remained unchanged from WRA.

3.1.3 Example FISK assessments

As an initial test of FISK, we selected five species from North America and three from Continental Europe (Table 2), plus an Asian species of recent particular concern (topmouth gudgeon, details of assessment given in Table 1). Of these, four species are large-bodied (at least facultative) piscivores: rainbow trout *Oncorhynchus mykiss*, brook trout *Salvelinus fontinalis*, largemouth bass *Micropterus salmoides*, European catfish *Silurus glanis*. The other five species are small-bodied, short-lived cyprinids that either guard or hide their eggs. Only one species, blageon *Leuciscus souffia*, was accepted as non-invasive. Four specimens of blageon were reported in a single survey of the upper Thames estuary (Araujo *et al.*, 1999), but the validity of this identification is questionable given the very restricted alpine (Switzerland, France, Italy, Austria) distribution of the species (where it is threatened) and the lack of any record of it in the aquarium/ornamental trade (Schwartz, 1998). The fish reported by Araujo *et al.* (1999) were probably mis-identified specimens of topmouth gudgeon, which have a similar appearance and were already present in the London area (Wheeler, 1998). With relatively close agreement between the two assessors, all

other species were rejected as potentially invasive (though northern redbelly dace *Phoxinus eos* was classed as as evaluate by one assessor). This reflects their current or potential status in the UK, i.e. all of these species have expanding ranges in the UK except northern redbelly dace, fathead minnow *Pimephales promelas*, and brook trout. Northern redbelly dace has not been reported to reproduce in Europe outside of artificial conditions, whereas fathead minnow is a commonly-used fish in scientific laboratories around Europe and is known to reproduce in garden ponds in England (G.H. Copp, personal observation) and Scotland (P. Maitland, personal communication). Fathead minnow is known to have established only a few populations in Continental Europe, where the species has yet to demonstrate invasive expansion. Introduction of brook trout began in the late 19th century, but the species is amongst those that has had difficulty to establish except in a few locations.

3.2 Hazard assessment (Phase II) – Invasive Fish Risk Assessment (IFRA)

Phase II, the Hazard Assessment phase (Appendix 1), is invoked for species of high (or unknown) potential risk in order to establish the probability of introduction and to provide a detailed analysis of the risks of establishment or impact, neither of which is provided for in the Hazard Identification phase. For the Hazard Assessment phase, we adapted the original EPPO (2000) standard, which consists of three parts (Introduction, Dispersal, Impact) and a scoring scale of 1 to 9. The purpose, and indeed practicality, of using such a wide scale was unclear, particularly in the absence of scoring guides. In adapting the EPPO scheme for freshwater fishes (Appendix 1), we used base scores of 1, 2 and 3 (with 'negligible' attracting a zero score, where applicable); these correspond to the Low, Medium and High risk rankings increasingly common to risk assessment strategies and methods (e.g. UK DoE, 1995; Groves *et al.*, 2001). To increase the objectivity of the assessment, we developed scoring matrices (similar to the score weighting sub-routines of FISK) for questions in which two or more variables contribute to the assessment. Explanatory guides have been provided with each question (and scoring thereof), and the assessor is expected to provide a brief rationale for the score given for each question. Consistent with the original EPPO standard, approximately equal weight has been assigned to each of the three sections.

Table 2. Fish Invasiveness Screening Kit (FISK) scores (total and topic sub-categories from hazard identification assessments carried out by the first (GHC) and third (REG) authors on freshwater fish species (not native to the British Isles) originating from Continental Europe (EU), North America (NA) and Asia (AS). Negative scores indicate species categorized as 'accepted' (low invasiveness risk) whereas all other species were 'rejected' (high risk).

Species		Total score		Aquaculture		Environmental		Nuisance	
Latin name	Common name	GHC	REG	GHC	REG	GHC	REG	GHC	REG
Leucaspius delineatus	sunbleak[EU]	26	24	17	17	24	19	2	2
Leuciscus souffia	blageon[EU]	-1	-2	-3	-3	3	3	0	1
Micropterus salmoides	largemouth bass[NA]	11	13	6	5	12	18	3	1
Oncorhynchus mykiss	rainbow trout[NA]	25	16	11	9	26	17	3	2
Phoxinus eos	northern redbelly dace[NA]	9	0	8	0	9	6	0	0
Pimephales promelas	fathead minnow[NA]	36	17	27	16	28	19	2	0
Pseudorasbora parva	topmouth gudgeon[AS]	36	38	26	32	29	28	2	2
Salvelinus fontinalis	brook trout	14	6	5	4	16	11	3	1
Silurus glanis	European catfish[EU]	25	17	14	12	23	19	3	3

3.2.1 Risk of Introduction (IFRA Part 1)

The Introduction section can be used to evaluate the risk of deliberate unauthorized and accidental (unintentional) introductions on either an organism or pathway (vector) basis. It is important that all potential pathways for accidental introduction are identified, and that the questions (1.06-1.15) are completed (where possible) for each pathway. Assessment of the risk of accidental introduction assumes that: a potential geographic donor region exists (Ricciardi and Rasmussen, 1998), and an association exists between the species and a potential pathway or vector. The risk will be influenced by the abundance of the species in the source area, which may vary seasonally, and the degree to which the species is commensal to humans (Ehrlich, 1986). These, combined with frequency of importation, will determine the risk of pathway exposure.

Introduction into the recipient country is assumed to be a function of whether appropriate quarantine procedures are in place in the source and/or recipient countries, the likelihood of an organism surviving and remaining undetected during transit and quarantine, and the probability of release into a suitable receiving environment. If an organism cannot survive the introduction phase from initial transfer (e.g. contamination) through to release into the environment, then it is assumed that no risk is posed. The identification of a new pathway or new source area for an invasive species should prompt a re-evaluation of introduction risk.

3.2.2 Risk of Establishment (IFRA Part 2)

This section assumes that a species requires similar environmental conditions to its native or naturalised range in order to establish. As in the Hazard Identification phase (Section 3.1), a climate matching model (e.g. CLIMEX, GARP) should be used, but where possible, micro-climatic or protected area conditions be taken into consideration. The similarity of climatic conditions and quality of the climate matching data is used to produce a climatic similarity index. As in the Hazard Identification phase (i.e. FISK), the absence of climatic matching is not an impediment; a precautionary approach is recommended and a default high score is applied.

For a species to be able to establish, IFRA assumes that all habitats (including hosts for parasitic species) necessary for completion of a full life cycle are present in the recipient area. Where these are not present the species evaluation ceases. Where a suitable habitat exists, establishment success will be influence by the availability of suitable food, the similarity of other abiotic conditions (Moyle and Light, 1996), the potential biological resistance (Baltz and Moyle, 1993), and the ability to reproduce in novel environments (i.e. size of founding population, sexual vs. gynogenetical reproduction, etc.).

Consideration is also given as to whether the receiving environment will be equally conducive to establishment than the source area, and the likelihood of successful eradication. Species that, as a result of their biological attributes and habitat requirements, are more difficult to eradicate should be assigned a higher risk score than those for which eradication would be environmentally feasible and socially acceptable (e.g. Mackenzie, 2003).

Table 3. Invasive Fish Risk Assessment (IFRA) protocol for hazard assessment (adapted from EPPO, 2000) of non-native freshwater fishes applied to topmouth gudgeon *Pseudorasbora parva*, which was introduced to one fish farm in Hampshire, so the risk assessment area is all counties of England and Wales outside of Hampshire. Pathway considered: Contaminant of fish consignments. Except as stated, scores are: L (low) = 1, M (moderate) = 2, H (high) = 3.

Question	Score	Comments
INTRODUCTION		
Deliberate Introduction		
Q 1.00	Unknown = Yes	Species imported in 1985; could still arrive in the country via imports of cyprinid fishes.
Q 1.01	Low = 1	Under current controls (i.e. ILFA) legal importation is unlikely
Q 1.02	Medium = 2	Depends on level of scrutiny of consignments at border
Q 1.03	LxM = 1	Scoring matrix outcome
Q 1.04	High = 3	Contaminant in legal movements of golden orfe *Leuciscus idus*; and is known to be abandoned by private fish owners (see Copp *et al.*, 2005b)
Q 1.05:	4	Deliberate introduction risk score = 4
Unintentional Introduction[†]		
Q 1.06	Yes	Species is known to be a contaminant in fish consignments (see Copp *et al.*, 2005a)
Q 1.07	Yes	Species is contaminant of fish rearing facilities
Q 1.08	High = 3	Seasonality = species is present at source all year, Abundance = medium to high
Q 1.09	Medium = 2	Fish transfers are normally restricted to September to April
Q 1.10	HxM = 3	Scoring matrix outcome
Q 1.11	No, High = 3	Quarantine procedures under section 30 (re: fish movements) apply to fish diseases only
Q 1.13	High = 3	Topmouth gudgeon is more tolerant of poor water quality conditions than the target species.
Q 1.14	No, High = 3	PER Q 1.10 Score = 3, Q 1.13 score = 3
Q 1.16	High = 3	Contaminant species is likely to enter the receiving water even if the consignment is graded
Overall Risk of Introduction Score: ('fish consignment contaminant' pathway only): 11 + 20 = 31		
ESTABLISHMENT		
Environmental Similarity		
Q 2.00	High = 3	Climate in England and Wales does not vary enough to exceed species' tolerances
Q 2.01	High = 3	Successful establishment in south and north of England evinces close climate match
Q 2.02	High = 3	Climatic match = high, but no data matching exercise yet undertaken, so quality = Low
Q 2.03	Highly = 3	Confirmed establishment in the England and Wales suggests high similarity.
Q 2.04	Yes	Confirmed establishment in the England and Wales since 1985 indicates all habitats present.
Q 2.05	Highly = 3	Confirmed establishment in the England and Wales suggests high likelihood.
Q 2.06	Unknown = 3	Confirmed establishment in the England and Wales suggests high likelihood.
Q 2.07	Low = 3	Given the organism's biological attributes and habitat requirements, what is the likelihood of Q 2.8
IMPACT ASSESSMENT		
Q 3.00	High = 3	Relatively little is known. No novel diseases reported, but hosts existing undesirable diseases, and is recently known to be the health host of a rosette-like agent of threat to native species (Gozlan *et al.*, 2005)
Economic Impact		
Q 3.01	Unknown = Yes	No published evidence is available, but this is implied in some accounts of apparent impacts
Q 3.02	High = 4	Direct or indirect monetary costs to ≥1 sectors on an international, long term scale
Q 3.03	Moderate = 2	Angling amenity, fish trade
Q 3.04	High = 3	Q 3.00 = high, so 2nd matrix: Q 2.08 = high, Vulnerable sectors = yes.
Q 3.05	High	Economic Risk Score = 9

Table 3. continued. Invasive Fish Risk Assessment (IFRA) protocol for hazard assessment (adapted from EPPO, 2000) of non-native freshwater fishes applied to topmouth gudgeon *Pseudorasbora parva*, which was introduced to one fish farm in Hampshire, so the risk assessment area is all counties of England and Wales outside of Hampshire. Pathway considered: Contaminant of fish consignments. Except as stated, scores are: L (low) = 1, M (moderate) = 2, H (high) = 3.

Question	Score	Comments
Environmental Impact		
Q 3.06	Yes	Reports of impacts are based on circumstantial and documented evidence (see Q 3.07)
Q 3.07	High = 4	Demonstrated facultative parasitism, omnivory and high densities suggest behavioural interference and competition suggest high environmental impact, especially as the intrinsic biodiversity value of waters is decreased when this species is present.
Q 3.08	Unknown = 3	There may be vulnerable groups, but these have yet to be identified.
Q 3.09	High = 3	Q 2.08 = high, Q 3. 05 = Yes
Q 3.10	High	Environmental Risk Score = 10
Social Impact		
Q 3.11	Unknown =Yes	No published evidence is available, but this is assumed consequent to environmental impacts
Q 3.12	High = 3	Environmental/economic impacts results in long term, irreversible effects at national level.
Q 3.13	High = 3	Q 3.04 = high, Q 3.08 = unknown
Q 3.14	Unknown = 3	Angling amenity and social perception of environmental quality (biodiversity) are at risk.
Q 3.15	High	Social Risk Score = 9
Dispersal and Spread		
Q 3.16	High = 3	We have estimated that at 60% of freshwaters in England and Wales are inhabitable.
Q 3.17	High = 3	Evidence exists for some natural dispersal, but this requires further study
Q 3.18	High = 3	Dispersal (as a contaminant) has been linked to human-assisted transfers
Q 3.19	High = 3	Q 3.17 = High, Q 3.18 = High
Q 3.20	Low = 3	The species is tolerant of poor water quality conditions and some chemicals.
Q 3.21	High	Risk of Dispersal score = 18
Q 3.22	High	Impact Assessment Score = 3 + 9 + 10 + 9 + 18 = 49
Total Risk	High	Introduction (31) + Establishment (21) + Impact Assessment (49) = 101

The number of questions answered is determined for: Introduction, Establishment, Impact Assessment

Count the number of 'Unknown' responses 'a' and calculate the uncertainty level surrounding the organism as: a ÷ 13 x 100 = 46.2%.

[†] Possible pathways: 1) Intentional transfer and introduction by humans, e.g. release of aquarium, garden or live bait specimens; 2) Contaminant of fish consignments; 3) Unintentional transfer and introduction by humans (e.g. angling gear, as live bait); 4) Unintentional transfer and introduction (of eggs) by birds; 5) Ballast water.

Impact Assessment (Part 3):
The third section of Hazard Assessment evaluates the potential adverse economic, environmental and social impacts of the species in the receiving environment based on the species' history of impact within its naturalised range, the presence of vulnerable sectors within the recipient area, and the likelihood of impact. When considering impact history, the severity of impact is assumed to be determined by the duration and spatial scale of the adverse impact experienced (following Parker *et al.*, 1999). In many cases, it will not be possible to predict the impacts arising from the introduction of a non-native species, but it may be possible to predict the likelihood of impact (Williamson, 2001). Particularly difficult to predict is the fish disease impact of non-native species, in particular those for which little or no pathology and parasitology information is available. Diseases are amongst the greatest, if not the greatest, impacts exerted by introduced fishes (e.g. Kennedy, 1993; Robertson and Austin, 1994; Gozlan *et al.*, 2005), having perceivable economic, environmental and

societal impacts. The first question of the Impact section aims to assess the species' potential as a host to novel or existing non-native parasites and pathogens.

The likelihood of adverse impact is treated differently for each category. The likelihood of a species having an adverse economic impact in the receiving area is estimated based on the presence of vulnerable economic sectors (CBD, 2001) and the risk of establishment. The likelihood of adverse environmental impact is evaluated according to past impact history (e.g. Ruesink *et al.*, 1995; Reichard, 2001) and the risk of establishment. The likelihood of social impact is considered to be determined by the likelihood of economic and environmental risk occurring in the receiving area.

The magnitude of adverse impact on the receiving environment will be affected by a species' dispersal characteristics. Consequently, the impact assessment section includes a series of questions relating to the species' likelihood and rate of natural dispersal and human-mediated spread. The likelihood of natural dispersal will be a function of the intrinsic rate of increase of the species (Crawley, 1986), the phenotypic plasticity of the species (ability to survive and reproduce under a range of

environmental conditions) and the dispersal mode of each of the life stages. The potential area exposed to natural dispersal will be dependent on the degree of connectivity of the water bodies (Unmack, 2001). The likelihood of human assisted spread will be a function of the sectoral use of the species, and its probability of accidental or deliberate transfer, e.g. use in biomanipulation, for angling amenity, abandonment by the general public (see Copp *et al.*, 2005b).

Finally, a major issue in risk analysis is that of uncertainty. Information on some species is sometimes, if not quite often, lacking. From a risk assessment point of view, the precautionary approach is taken and a 'poorly-studied' species is ranked as high risk. However, from an analytical point of view, especially for identifying gaps in knowledge to advise future research and policy decisions, it is important to gauge the level of confidence associated with an assessment. As a simple measure, we have suggested a basic calculation of the proportion of questions answered 'Don't know'. However, an alternative could be to qualify each response (yes/no, low/medium/high) with a rapid assessment of confidence — e.g. The level of confidence I place on my response is: 1) low; 2) medium; 3) high.

4. Concluding remarks

Increased global trade, transport and tourism have provided greater opportunity for organisms to move beyond their natural ranges, and invasive species have been recognised as one of the most significant influences on biodiversity and environmental change worldwide (e.g. Ciruna *et al.*, 2004). The impacts of non-natives are considered to be relatively more important in the freshwater environment (particularly lakes and temperate streams) than the terrestrial environment because of their relative geographic isolation and as a result of the extensive intentional and accidental introductions of aquatic organisms (e.g. Moyle, 1999). In Europe, lakes and rivers (along with islands and inshore marine areas) are considered to be amongst the most vulnerable ecosystems to non-native species (Heywood, 1995). Currently, UK law does not permit a blanket ban on the importation of non-native organisms although there is a general prohibition on the introduction of all non-native animal species into the wild (UK Defra, 2003a). Use of a robust, scientifically-based risk assessment framework will facilitate pro-active management of non-native freshwater fish with an emphasis on prevention (border and internal control measures) rather than cure (CBD, 2001).

Risk assessment is a well-established discipline in natural resource production sectors such as forestry, agriculture and marine fisheries in which the adverse economic impact of pests and weeds has been readily demonstrable and has been the underlying motivation for the development of risk strategies. The proposed framework for non-native freshwater fishes is intended to serve a similar function and the framework requires application and validation in order to test the assumptions used to formulate questions and score weightings. By incorporating semi-quantitative elements into the screening assessment, the proposed risk framework is expected to develop into a scientifically robust scheme that incorporates, as sub-routines, more sophisticated data analysis techniques to provide more objective responses than those based entirely on expert judgement. Whilst still conceptual in nature, the framework provides transparency and consistency and enables the assessment of the relative risk of a species' introduction, establishment and impact facilitating more informed policy development and management.

Both of the tools proposed here rely on the assumption that climate matching will provide a good prediction of potential for establishment and impact. Similarly, both rely on previous impact history as a predictor for invasiveness. There are shortcomings with these assumptions, particularly when considering species that have not been widely introduced outside their native ranges. Impact is likely to be a function of the properties of the invaded ecosystem

(Ricciardi, 2003), and furthermore, a species' interaction with its environment may differ in different geographical regions — e.g. pumpkinseed *Lepomis gibbosus*, which is invasive in southern (Godinho and Ferreira, 1998) but not northern Europe (Copp *et al.*, 2004) — nonetheless, the species scores relatively highly at 29 (G.H. Copp, single assessment not included in Table 2). The absence of invasive behaviour in other countries may be assumed to indicate a low risk, it does not indicate a zero risk, particularly if there is little data available. Indeed, current predictions for climate change under scenarios of global warming could lead to pumpkinseed becoming invasive in Southern England (Klaar *et al.* 2004). Therefore, when completing such assessments, it is important that areas of uncertainty are acknowledged and that the precautionary approach is applied both in terms of applying the data available, and in interpreting the result.

Neither of the two phases of the proposed framework take directly into account the potential for a species to emerge as invasive some time after establishment, though this is indirectly assessed through evaluation of the species history of invasions elsewhere in its introduced range. And, an inherent part of the UK risk strategy (UK Defra, 2002) is the Review and Reporting stage, which ensures that risk assessments are not static, but subject to modification when the circumstances surround a particular species change. Invasions by species do not proceed at the same rate, and species may naturalise and persist at low levels (during a lag phase) before undergoing population increase. This phenomenon has been observed in tench *Tinca tinca* and Eurasian perch *Perca fluviatilis* in South Africa and Australia (Bruton, 1986), and the Chinese mitten crab *Eriocheir sinensis* in England, where an extended, post-introduction lag phase (Crooks and Soule, 1999) was followed by a dramatic population increase during the drought conditions of 1989-1992, which facilitated greater settlement of young crabs (Attrill and Thomas, 1996). These examples emphasize the point made by Smith *et al.* (1999), that examination of existing non-native species warrants equal consideration, and in some circumstances greater attention, as those not yet introduced.

The ecological and economic costs of invasion are high (Ricciardi and Rasmussen, 1998). A comprehensive risk assessment framework must include risk analysis, risk communication and risk management. To be effective, mechanisms are required to feed the results of the assessment into a management system to require emergency response, further evaluation and research, ongoing management, and modifications to policy and legislation. Management decisions will be determined by

the costs and benefits of any proposed options, and it is important to note that neither the hazard identification nor hazard assessment stages of our framework include a cost benefit, or cost effectiveness analysis. This must be undertaken as part of a separate process. It is therefore recommended that the results obtained from these protocols be interpreted cautiously with emphasis given to preventing the entry of new organisms (as recommended by the CBD, 2001, guidelines) through pre-border screening, rather than remaining focused on the prevention of introduction into the wild, as is the current focus in England.

As the proposed risk assessment framework for non-native fishes was being completed, the UK government commissioned the development of a generic non-native species risk assessment scheme, based on similar EPPO protocols as presented here (Appendix 1), that is applicable to all non-native plants and animals. In the resulting generic scheme (UK Defra, 2005), taxon-specific sub-routines (plug-ins), such as FISK (Table 1), are used to ensure that the generic scheme is adapted to each taxonomic group. Indeed, other adaptations of WRA (Pheloung *et al.*, 1999), developed specifically for the UK generic framework, include versions for assessing invasiveness in Amphibia, marine invertebrates and marine fish (UK Defra, 2005). Similar to FISK (Table 2), these other adaptations of WRA have not been validated, but they represent an important step forward in the development of risk assessment methodologies for aquatic species. The version of FISK presented here is currently being converted into a standard-alone computer module that will be made available along with this report on Cefas web pages in due course.

5. Acknowledgements

6. References

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Appendix 1.

Invasive Fish Risk Assessment (IFRA) protocol for hazard assessment of non-native freshwater fishes, as adapted from the EPPO (2000) pest risk analysis standard (PK 5/1-4). L = low, M = moderate, H = high. Unless otherwise stated, scores are: L = 1, M = 2, H = 3. Scoring instructions and explanations are provided as required. To deal with uncertainty (precautionary approach), an 'unknown' response is by default equated with a 'yes' response, as appropriate to the question. A brief explanation for the score given should be provided by the assessor with each response.

INTRODUCTION
Deliberate Introduction
To estimate the risk of introduction as a result of deliberate unauthorized importation, complete Q 1.0 – Q 1.05.

Q 1.00: Is the organism likely to be imported (either legally or illegally) into the recipient area?
Scoring Instructions:
 illegally Yes = Go to Q 1.01 legally Yes = Go to Q 1.04
 Neither = Go to Q 1.06 Unknown = Yes
Explanation: Is the species popular in aquaculture, angling, or the ornamental/aquarium trade? Is it considered useful for biological control purposes or known to be targeted in wildlife trade activity? Is the species offered for sale on the international market?

Q 1.01: What is the likelihood of the organism being illegally imported into recipient area? (L, M, H)
Explanation: Likelihood will be determined by the popularity of the species, the ease of transport and disguise, and the market value of the species.

Q 1.02: What is the likelihood of detection of the organism during transit? (L, M, H)
Explanation: Probability of detection will be determined by whether there are border screening processes in place for the route by which the organism is likely to be smuggled in, how physically obvious the organism is, how similar it is to native species, the required mode of transport, i.e. Is it dependent on transport in water? If available, then historical information should be used to identify interception/detection rates.

Q 1.03: Deliberate Importation Risk score
  (use the matrix below):

Likelihood of import (Q 1.01):		Low	Medium	High
Likelihood of detection (Q 1.02) =	Low:	M	H	H
	Medium:	L	M	H
	High:	L	L	M

Q 1.04: Estimate the likelihood of organism's (illegal) release into a suitable receiving environment. (L, M, H)
Explanation: Probability will be influenced by sector use and organism size. The probability of successful deliberate introduction to a suitable water body for: Aquaculturalists and for biocontrol: Likely to be High; Ornamentalists and hobbyists: Moderate; Scientists: likely to be low. Organism size: For species that attain a small ultimate size (<5 cm length excluding tail): Low; For species that attain a moderate ultimate size (5-10 cm length excluding tail): Moderate; For species that attain a large ultimate size (>10 cm length excluding tail): high

Q 1.05: Deliberate Introduction Risk Score = Q 1.03 + Q 1.04

Unintentional Introduction
Instructions: Identify all possible pathways of organism importation. These will vary according to the organism life-stage and source area. For each pathway (e.g. ballast water, accidentally brought in with aquaculture and aquarium trade), complete Q 1.06 - Q 1.16.
Please note: an alternative approach is to take a pathway (vector) focused approach. This would require identifying a pathway which may pose a high risk of aquatic organism contamination and undertaking a systematic analysis of the pathway in the source region to identify: all known invasive aquatic organism in the source region and their likelihood of association with the pathway. For example for a given country, identify the species most likely to be introduced via a certain pathway (e.g. aquatic plants, ornamental fish releases). Once this analysis is complete, then complete Q 1.06 – Q 1.16.

Q 1.06: Could the organism be accidentally imported into the recipient area on the pathway in question?
Scoring Instructions:
   Yes = Go to Q 1.07 No = End evaluation of this pathway
   Unknown = Yes

Q 1.07: Is the organism likely to be associated with the pathway at the pathway's source?
Scoring Instructions:
   Yes = Go to Q 1.08   Unknown = Yes
   No = End pathway evaluation
Explanation: Historical interception data should be reviewed where possible. Consider all life stages of the organism and the importance of life history (i.e. Is contamination likely to be determined by the life history characteristics of the organism, such as large scale dispersal events?). Does the organism show a convincing temporal and spatial association with the pathway?

Q 1.08: What is the likelihood the organism will be associated with the pathway at its source? (use matrix below):

	Seasonality:	Seasonal	All year
Abundance =	Low:	L	M
	Medium:	M	H
	High:	H	H

Explanation: For there to be an association the vector must be exposed to the organism of interest. Rate of exposure will be influenced by the abundance of the organism that may vary seasonally. For example is abundance increased at certain times of year or do changes in the behaviour of the animal increase the likelihood of association. Scoring: L = low abundance, limited to certain times of year only; M = low abundance, all year, or moderate abundance, seasonally determined; H = moderate abundance all year, or high abundance all year, or high abundance, seasonally determined.

Q 1.09: With what frequency is the vector imported to the recipient country?
Scoring instructions:
   L = 1-2 months of year, M = 3-7 months of year,
   H = 8 or more months of year
Explanation: Volume of commodity imported may also be relevant, e.g. large consignments are received during a relatively short period of the year, in which case an intermediate (M) score may be more appropriate.

Q 1.10: Pathway Exposure Risk (PER) L , M or H (use the matrix below):

Likelihood of association (Q 1.08):	Low	Medium	High
Likelihood of import (Q 1.09) = Low:	L	L	M
Medium:	L	M	H
High:	L	H	H

Explanation: Pathway exposure risk is the risk posed by the pathway given the frequency of import and the likelihood that the organism will be associated with the pathway in question.

Q 1.11: Are the goods subjected to quarantine procedures in the country of origin?
Scoring instructions:
   Yes = No score, Proceed to Q 1.12
   Unknown = No
   No = Score is determined by PER rating from Q 1.10 using conversion given here below, then proceed to Q 1.13: PER rating = L, then Q 1.11 score = 2; PER rating = M, then Q 1.11 score = 3; PER rating = H, then Q 1.11 score = 3
Explanation: Quarantine procedures may include surveillance, sampling of goods, sanitary treatment and must be effective against the relevant life stage of the organism in question. The scoring assumes that an absence of quarantine procedures increases the risk of introduction. If the country of origin is unknown, then one assumes no quarantine procedures were used.

Q 1.12: If response to Q 1.11 was Yes, then what is the likelihood of the organism surviving the quarantine procedure/or remaining undetected? (L, M, H)
Explanation: The treatment must be proven to be effective against the organism in question. Probability of detection will be determined by how physically obvious the organism is, the required mode of transport, i.e. Does the organism's survival rely on transport in water? If available, historical information should be used to identify interception/detection rates.

Q 1.13: What is the likelihood of the organism surviving in transit? (L, M, H)
Explanation: This will be influenced by travel time and mode of transport.

Q 1.14: Are the goods subjected to quarantine action in the receiving country?
Scoring instructions:

Yes = 0, proceed to Q 1.15

No = see below   Unknown = No

No = The score awarded here will vary according to whether a Yes or No answer was given in Q 1.11. Refer to matrices below for scoring (Once completed, proceed to Q 1.16).

If response to Q 1.11 was 'Yes' and to Q 1.14 was 'No', then use matrix here below:

Likelihood of surviving quarantine (undetected):		**Low**	**Medium**	**High**
Likelihood of survival in transit =	Low:	L	L	M
	Medium:	L	M	H
	High:	L	H	H

If response to Q 1.11 was 'No' and to Q 1.14 was 'No', then use matrix here below:

PER Score from Q 1.10:		**Score = 2**	**Score = 3**
Likelihood of survival in transit (Q 1.13) =	Low:	M	M
	Medium:	M	H
	High:	H	H

Explanation: The treatment must be proven to be effective against the organism in question. The score provided for this question is weighted according to whether quarantine action was taken before leaving the source country. The score is determined by combining the likelihood of surviving the quarantine procedure without detection, and the likelihood of survival in transit, or, by the pathway exposure risk and the likelihood of survival in transit.

Q 1.15: If response to Q 1.14 was YES, then: What is the likelihood of the organism remaining undetected during the quarantine action? (L, M, H)
Explanation: Probability of detection will be determined by how physically obvious the organism is, the required mode of transport, i.e. Is it dependent on transport in water? If

available, then historical information should be used to identify interception/detection rates.

Q 1.16: What is the probability of the release of the organism into a suitable receiving environment in the recipient area? (L, M, H)
Explanation: Probability will be influenced by pathway ' 'use'. For example the probability of successful (accidental) introduction to a suitable water body: For Angling users is likely to be Low (as contamination is likely to be of waders, nets, rods etc), or Moderate (if contamination is of bait fish supplies). For ornamental users, it is likely to be Moderate as contamination is likely to be in water or in aquatic plants (kept moist during transit). For Aquaculture and Aquarist users, it is likely to be High as contamination is likely to occur in water.

Risk of Introduction Score (for each pathway):

Overall Risk of Introduction = Deliberate + Accidental[p]
([p] = all pathways)
ESTABLISHMENT
Instructions: For each species complete Q 2.0 – Q 2.8

Environmental Similarity

Q 2.00: How similar are the climatic conditions that would affect the organism's establishment (survival/reproduction) in the recipient area and the source region? (L, M, H)
Explanation: A Climatic modelling programme (such as CLIMEX or GARP) should be used where possible. The climatic conditions in the recipient area should include protected area conditions. Where there is evidence of phenotypic plasticity within the native range, a high score should be applied. If climate matching is not possible due to an absence of data, then a default score will be applied (see Q 2.02)

Q 2.01: What is the quality of the climate matching data? (L, M, H)

Q 2.02: Climatic similarity index
Scoring Instructions: Using the responses to Q 2.00 and Q 2.01 determine the Climatic similarity index using the matrix here below (if climatic matching is not possible, then use H [high = 5] as a default response):

Climate match:	Low	Medium	High
Quality of climate data used = Low:	M	H	H
Medium:	L	M	H
High:	L	M	H

Q 2.03: How similar are other abiotic factors in the recipient and source areas? (L, M, H)

Explanation: The major abiotic factors to be considered are salinity, pH, water flow, oxygen content and disturbance levels.

Q 2.04: Are all habitats that are necessary for the completion of the organisms life cycle available in the recipient area?

Scoring Instructions:
   Yes = Go to Q 2.05   Unknown = Yes
   No = Cease species evaluation

Explanation: If considering parasitic or symbiotic species, then potential host availability should be evaluated. Consider the habitat requirements for growth, reproduction and spawning.

Q 2.05: What is likelihood the organism will colonize and maintain a population? L, M or H

Explanation: Consider the frequency of introductions (i.e. 'propagule pressure'), availability of food sources, possibility of encountering biotic environmental resistance (predator-prey interactions and competition), and the ability to reproduce (determined by reproductive mode, and size of the founding population).

Q 2.06: If there are differences between the environmental conditions of the recipient and source areas, then what is the likelihood the recipient area will be more favourable for establishment potential? (L, M, H = high or unknown)

Explanation: Consider here whether establishment potential is enhanced as a result of environmental factors (more favourable temperatures, fewer predators or potential competitors) or cultivation practices. If unknown, treat as high likelihood.

Q 2.07: Given the organism's biological attributes and habitat requirements, what is the likelihood of its successful eradication from the recipient area.

Scoring Instructions:
   Use matrix here below
   (note that for this matrix: L = 3, M = 2, H = 1):

Water types:	Isolated systems:		Connected systems:			
Species type	Pond (‹2ha)	lake/ wetland	lake/ wetland	river/ stream	canal	estuary
Limnophilic:	H	L	L	L	L	L
Rheophilic:	H	M	L	L	M	L
Generalist:	H	L	L	L	L	L

Explanation: The likelihood of eradication is assumed to vary according to habitat guild and is a function of the size and connectivity of water body/water course.

Q 2.08: Total Establishment Risk score:
   $\sum$Q 2.00 to Q 2.07 (L = 7-12, M = 13-17, H ≥ 18)

IMPACT ASSESSMENT

Instructions: For each species complete Q 3.00 – Q 3.16.

Q 3.00: Estimate the severity of disease risk posed by the organism.

Scoring Instructions:
   Use a disease risk assessment sub-routine to provide a risk ranking of (L, M, H)

Explanation: Parasites and pathogens may have an impact of equal or greater importance than the introduced species itself, including environmental, economic and possibly even social levels. This assessment should be undertaken by a competent fish disease specialist, encompassing both pathology and parasitology.

Economic Impact

Q 3.01: Is there a history of economic loss caused by the organism within its naturalised range?

Scoring Instructions:

   Yes = Go to Q3.02   No = Go to Q3.03

   Unknown = Yes

Explanation: Economic impacts may include loss of earnings due to reduced productivity, costs of mitigation, remediation and eradication, research costs, reduced earnings, impacts to export markets, banning of sale of commercially popular species etc. The assessment of adverse economic impact should be undertaken by a competent economist.

Q 3.02: Estimate severity of economic loss caused by the organism within its naturalised range.

Scoring Instructions:

   Select 1 of the five categories from list below.

Explanation: It is assumed that economic impact will be a function of the duration of the impact and the scale (local, regional, national). All sectors and all direct and/or indirect costs should be included, for example: commercial, recreational and traditional fisheries, aquaria/ornamental fish trade, human and animal health.

Examples:

Score = 0: No perceivable economic impact

Score = 1: Organism resulted in direct or indirect monetary costs on a localised, short term scale.

Explanation: Identification of newly established fish species in one small pond. The pond, which is regularly stocked with coarse fish and is popular with local anglers, is temporarily closed while the new invasive species is eradicated. Consequent loss of income to local village from loss of angling fees and costs of eradication and restocking.

Score = 2: Organism resulted in direct or indirect monetary costs to ≥1 sectors on a regional, short term scale.

Explanation: Example of establishment of an exotic fish species in rivers in Southern Canada. Following initial establishment the introduced species undergoes a population explosion with consequent reductions in abundance of other fish species. Costs are incurred directly through a loss in revenue from angling and tourism, and research and control attempts. Four years after establishment, population growth returns to normal levels, and the abundance of other fish species increases. Angling and tourism activity returns and requirements for funding for research and control ceases.

Score = 3: Organism resulted in direct or indirect monetary costs to ≥1 sectors on a regional, long term scale.

Explanation: Example of introduced fish species establishes in multiple catchments in northern Spain. A benthic feeder it causes significant sediment suspension, reducing habitat quality for other fish and plants resulting in a reduction of abundance of high value angling species, and rare native species. Costs of survey, containment, mitigation and research into control techniques are on-going.

Score = 4: Organism resulted in direct or indirect monetary costs to ≥1 sectors on a national, long term scale.

Explanation: Infection of high value commercial freshwater species with trematode of significant human health importance as a result of illegally imported live fish stock. Results in suspension and eventual ban on accepting imports of all host species and similar fishes from this country.

Q 3.03: Are there any vulnerable sectors or markets in the recipient country potentially placed at economic risk by the establishment of this organism?

Scoring Instructions:

   No = 0   a few = 1   moderate number = 2

   many = 3

Explanation: For example, are there sectors or markets that are likely to be impacted by to the organism during the invasion process?

Q 3.04: What is the likelihood the organism will cause economic impact in the recipient area?

Scoring Instructions:

   Use the matrix below if Q 3.00 = L:

Establishment risk (from Q 2.08):	Low	Medium	High
Vulnerable sectors = Yes:	L	M	H
No:	L	L	M
Unknown:	L	M	H

Use the matrix below if Q 3.00 = M or H:

Establishment risk (from Q 2.08):	Low	Medium	High
Vulnerable sectors = Yes:	M	H	H
No:	L	M	H
Unknown:	M	H	H

Explanation: It is assumed that the likelihood of impact is a function of the presence of vulnerable sectors and risk of establishment. Vulnerability will be influenced by the risk of disease transmission, so the risk of economic impact is expected to increase accordingly. Choice of the matrix is thus influenced by the outcome of Q 3.00 (if L, then use upper matrix; if M or H, then use lower matrix).

Q 3.05: Economic Risk Score: ∑ Q 3.02 to Q 3.04
Explanation: Typical totals are expected to be: Low = 1-3, Moderate = 4-6, High ≥7)

Environmental Impact

Q 3.06: Does organism have a history of environmental impact within its naturalized range?
Scoring Instructions:
    Yes = Go to Q 3.07   No = Go to Q 3.08
    Unknown = Go to Q 3.08
For example, does the organism modify or damage vulnerable habitats, have significant impacts on native wildlife

Q 3.07: Estimate the severity of environmental impact caused by the organism within its naturalised range.
Scoring Instructions:
    Select 1 of the 4 categories from list below:
Explanation: Impacts may include predation, competition, reduced habitat quality, genetic effects such as hybridization or introgression, introduction of parasites or pathogens (refer back to Q 3.00 for disease risk ranking), changes in disturbance regimes, resource pools and supply rates etc. Congeners and species with a similar eco-morphology may be particularly susceptible. If the species acts as a major predator on native species with few predators, this would also be a significant impact.
Examples:
Score = 1: Organism is recorded to have had direct or indirect sub-lethal impact at individual level.
Explanation: Species may directly or indirectly cause behavioural change, reduced growth or reproduction on individuals within a population.
Score = 2: Organism is recorded to have had direct or indirect impact at the population level.
Explanation: Impacts are felt in a localized area and are reversible. May include changes in population abundance, growth or distribution.

Score = 3: Organism is recorded to have had direct or indirect impact at the community level.
Explanation: Impacts are felt at a regional level, and may include local extinction, reductions in local native species richness, local dysfunction of communities and ecosystems. Impacts are irreversible.
Score = 4: Organism is recorded to have had direct or indirect impact on ecosystem function or processes at the national level.
Explanation: Impacts are important nationally, and are irreversible. May include national extinction of species or impairment of ecosystem function.

Q 3.08: Are there any vulnerable groups in the recipient country potentially placed at risk by the establishment of this organism?
Scoring Instructions:
    Yes = 3   Unknown = 3   No = 0
Explanation: For example threatened species, habitats or ecosystem types that are likely to be exposed to the pest during the invasion process. Are there species that may be exposed to significantly increased levels of predation or competition (for food or habitat), or are they any closely related taxa or species with a similar ecology/morphology that may be particularly susceptible.

Q 3.09: What is the likelihood the organism will result in environmental damage in the recipient area?
Scoring Instructions: Use the matrix below:

Establishment risk (from Q 2.08):	Low	Medium	High
Environmental impact history (Q 3.06) = Yes:	L	M	H
No:	L	L	M
Unknown:	L	M	H

Explanation: The likelihood of environmental damage is assumed to be a function of past history of environmental impact and the risk of establishment.

Q 3.10: Environmental Risk Score: ∑ Q 3.07 to Q 3.09
Explanation: Typical totals are expected to be: Low = 1-3, Moderate = 4-6, High ≥7)

Social Impact

Q 3.11: Is there a history of social impact caused by the organism within its naturalised range?

Scoring Instructions:

Yes = Go to Q3.12 No = Go to Q3.13 Unknown = Yes

Explanation: Social impact is defined as the consequences to human populations of any public or private actions that alter the ways in which people live, work, pay, relate to one another, organise to meet their needs and generally cope as members of society. Includes cultural impacts involving changes to the norms, values, and beliefs that guide individual action*. Social effects may arise as a result of impacts to commercial or recreational values, life support/human health, biodiversity, aesthetics or beneficial uses. The assessment of adverse social impact should be undertaken by a competent social scientist.

Q 3.12: Estimate severity of social impact caused by the organism within its naturalised range.

Scoring Instructions:

Select 1 of the 3 categories from the list below:

Explanation: When considering social impacts, effects to human and animal health, cultural values, quality of life, should be considered. Examples are provided below: The significance of social impact is assumed to be a function of duration and spatial scale.

Examples:

Score = 1: Organism presence, or environmental/economic impacts resulting from the organism, results in long term effects within a local community.

Explanation: Introduction of invasive fish species into two small water bodies resulted in treatment of infested sites. Treatment required closure of access by members of the public to these favoured water spots. Dead and dying fish caused distress to members of the public.

Score = 2: Organism presence, or environmental/economic impacts resulting from the organism, results in long term, irreversible effects at a regional level.

Explanation: Aquaculture in the eastern USA is disrupted by the introduction of a fish disease. Movement controls are enforced resulting in reduced access to water bodies by members of the public. Dead and dying fish create human health hazard and cause distress to members of the public. Public concern regarding the potential human health impacts of the piscicide used to destroy the fish and mounting public pressure to cease the eradication programme.

Score = 3: Organism presence, or environmental/economic impacts resulting from the organism, results in long term, irreversible effects at a national level.

Explanation: Illegal importation and release of popular angling fish species infected with highly pathogenic parasite results in the death of fish throughout the country. Results in a closure of local and regional recreational fisheries, leading to changes in past-time activities and behaviours and/or a loss of cultural identity.

Q 3.13: What is the likelihood the organism will result in social impact in the recipient area?

Scoring Instructions:

Use the matrix below:

Economic risk score (from Q 3.04):	Low	Medium	High
Environmental risk score = (from Q 3.10) — Low:	L	M	H
Medium:	M	H	H
High:	H	H	H

Explanation: It is assumed that environmental and economic impact (expressed as the Economic Risk and Environmental Risk scores) will be predictive of social impact, e.g. the likelihood of social impact from previous history. To avoid choosing whether Environmental or Economic risk should be ranked higher when determining the social risk likelihood, in every case, the higher of the two ratings is assigned in the matrix (for example, if Environmental risk is L and Economic Risk is M, then the rating = M).

Q 3.14: Are there any vulnerable groups in the recipient country potentially placed at risk by the establishment of this organism?

Scoring Instructions:

Yes = 3   Unknown = 3   No = 0

Explanation: For example, are there groups (for example subsistence fishers whose livelihood is dependent on catching a certain quantity of fish) likely to be exposed to, or affected by the organism during the invasion process.

Q 3.15: Social Risk Score: ∑ Q 3.12 to Q 3.14

Explanation: Typical totals are expected to be: Low = 1-3, Moderate = 4-6, High ≥7)

* Guidelines and Principles for Social Impact Assessment. Prepared by the Interorganisational Committee on Guidelines and Principles for Social Impact Assessment. May 1994. http://www.nmfs.noaa.gov/sfa/social_impact_guide.htm

Dispersal and Spread

Q 3.16: What is the availability of suitable habitat within the recipient area? (L, M, H)

Explanation: Consider here the abundance, distribution and connectivity of suitable sites. For parasitic/symbiotic species consider the availability of potential host species. For example: a large number of potential sites, distributed throughout the country, should receive a higher score than a low number of potential sites concentrated in one region.

Q 3.17: What is the likelihood of spread via natural dispersal (L, M, H)

Explanation: The likelihood of spread via natural dispersal will be determined by the intrinsic rate of increase of the species (fecundity, survivorship and development rate), the plasticity of the species, the dispersal mode of each of the life stages (e.g. live-bearing, or broadcast spawners), the environmental tolerance of the species (at each of the life stages), habitat requirements and biological interactions, and the degree of isolation of breeding sites. Consider whether the primary mode of spread is by passive dispersal of eggs, passive or active dispersal of larvae, active dispersal of adults due to density dependent effects or migration for spawning, smoltification or feeding. Consider also whether the vulnerable water bodies (or connected habitats) are subject to regular periodic flooding events, and any other natural routes of dispersal. The likelihood of spread will be highest for highly fecund species that can tolerate a wide range of environmental conditions, that actively disperse and that inhabit open fast flowing water bodies. The natural dispersal likelihood will be lowest for species of low environmental tolerance that passively disperse and inhabit closed water bodies.

Q 3.18: What is the likelihood of spread via human assisted means (L, M, H)

Explanation: This will be a function of the sectoral "use" of the species and its probability of accidental and deliberate transfer. Accidental transfer will be more likely the more common and environmentally tolerant the species is. Deliberate transfer will be a function of the level of popularity of the species and possibly also environmental tolerance. As a general guide it is assumed that the risk of accidental and deliberate transfer by: Anglers is high; Aquaculturalists is moderate. The risk of accidental transfer by: Ornamentalists and aquarists is regarded as low and for deliberate transfer as high. For researchers it is assumed that the risk of accidental transfer is moderate, and for deliberate transfer,

low. For biocontrol purposes it is assumed that the risk of accidental transfer is low, and deliberate transfer is high. When determining the likelihood of spread, these risks should be weighed against the environmental hardiness of the species (probability of surviving transfer).

Q 3.19: What is the potential rate of spread in the recipient area?

Scoring Instructions:

Use the matrix below:

Human assisted dispersal (Q 3.18):	Low	Medium	High
Natural dispersal (Q 3.17) = Low:	L	M	M
Medium:	M	H	H
High:	M	H	H

Explanation: Rate of spread will be a function of the likelihood of human assisted and natural dispersal.

Q 3.20: Once established, how feasible is containment? (L = 5, M = 3, H = 1)

Explanation: Is there targeted surveillance for the species, how soon after establishment is identification likely to occur. Are control techniques available and cost effective, and what are the non-target effects. Containment in estuarine sites may be possible, depending on mode of dispersal, whereas containment in open water is low.

Q 3.21: Risk of Dispersal score = Σ Q 3.16 to Q 3.20

Q 3.22: Impact Assessment Score = Σ Q 3.00 + Q 3.05 + Q 3.10 + Q 3.15 + Q 3.21

Total Risk = Introduction + Establishment + Impact Assessment

- Breakdown Scores can be calculated for: Introduction Risk, Establishment Risk, Impact Risk.

- The number of questions answered is determined for: Introduction, Establishment, Impact Assessment.

- Count the number of 'Unknown' responses 'a' and calculate the uncertainty level surrounding the organism as: a ÷ 13 x 100 = ___ %.

Cefas