Early detection and rapid response to invasive species at a national level along risk pathways for selected productive sectors in Mexico

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"Aumentar las capacidades de México para manejar especies exóticas invasoras a través de la implementación de la Estrategia Nacional de Especies Invasoras

<u>Primer informe de actividades presentado a</u>

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1 Introduction

The Global Environment Facility (GEF) through the United Nations Development Program is funding a program to enhance national capacities to manage invasive alien species (IAS) by implementing the Mexican National Strategy for IAS, which is being coordinated by the Mexican National Commission for Knowledge and the Use of Biodiversity (CONABIO) and the National Commission for Protected Areas (CONANP). The focus of the program is on prevention and rapid response to incursions of new species, rather than management of long-standing problems caused by IAS already established in Mexico. The expected outcomes of this area of the GEF project are to strengthen national institutional capacity to reduce risks from IAS, particularly on Mexico's biodiversity and vulnerable ecosystems, by improving prevention of incursions and establishment of IAS associated with four productive sectors, viz. the aquarium trade, aquaculture, trade in wildlife and trade in forest products.

As part of this program *Kurahaupo Consulting* was commissioned to provide guidance on how to develop a national EDRR concept, recommend specific activities including costs and times, responsibilities to be undertaken during the FSP to strengthen national capacities and processes in relation to the aquarium trade, aquaculture, trade in wildlife, and trade in forest products primarily as they affect bidoversity.

The main focus of the report is on risks from species within the four productive sectors to national biodiversity, while the main focus of the management needs is on what might be implemented during the FSP.

2 Objectives

To provide guidance on how to develop a national EDRR concept, recommend specific activities including costs and times, responsibilities to be undertaken during the FSP to strengthen national capacities and processes by discussing:

- Introduction pathways related to the selected productive sectors.
- The effectiveness of existing national systems for the detection and treatment of IAS that may impact on biodiversity.
- An EDRR national system and proposed interventions to strengthen coordination, processes and skills for the prevention and control of IAS in the selected productive sectors.
- Risks and risk responses with guidance on costs, deadlines and responsibilities.
- Measurable indicators to monitor progress of the proposed activities

3 Background information

3.1 IAS in Mexico

Mexico has a long history of contact, colonisation and trade with the rest of the world. It has long land borders (3269, 871 and 251 km with the USA, Guatamala and Belize, respectively) with 45 legal crossing points, long coastlines (11,000 km) over two oceans, 90 ports (47 in the Pacific and 53 in the Gulf of Mexico and Caribbean) with over 6000 ship arrivals per year, and has substantial regulated, unregulated (and sometimes illegal) interchange of people (over 300 million crossings per year) and goods at many points of entry.

Mexico is a highly biodiverse country. Flores Martínez et al. (2013) claim Mexico has 9% of the world's species with over 50% being endemic. They record 23 424 species of vascular plants, 66 800 invertebrates and 5488 species of vertebrates. The latter inludes 2695 species of fish, 1096 birds, 804 reptiles, 361 amphibians, and 535 mammals.

Numbers of non-native species in Mexico vary between authorities but non-native species for most taxa represent less than 5% of all species in Mexico. This proportion is much lower than for islands (e.g. New Zealand with 40% for vascular plants) or for most states in the USA (e.g. California has 17.5% for vascular plants), but seems typical of other tropical countries (e.g. tropical Africa with 2.2% or Panama with 3.6% for vascular plants) (Vitousek et al. 1997).

CONABIO (2012) has collated the numbers of invasive species across taxa known to be present in Mexico (Table 1), and by 2012 had listed 1272 exotic species of which 570 were identified as IAS[1].

Table 1. Non-native species recorded in CONABIO's information database (as of 2012).

Taxon	No. invasive species	No. exotic species either not invasive or under review	Total non-native species
Microbes	1	2	3
Fungi	11	0	11
Algae	47	71	118
Plants	266	535	801
Molluscs	18	5	23
Crustacea	36	5	41
Insects	35	3	38
Other invertebrates	29	28	57
Fish	90	12	102
Amphibians	4	1	5
Reptiles	6	3	9
Birds	8	3	11
Mammals	19	2	21
TOTAL	570	668	1219

[1] Making lists of is always a 'work in progress' and so there is always inconsistences between such lists.

3.2 Black lists

A black list names species (or classes of organisms) that are prohibited from import, or, as a second category, signals that a species already present in the country is of particular concern and should be managed. Most black lists by implication usually do not include IAS already legally present in the country unless importation of more of such species presents some transparent additional risk. All is permitted unless forbidden! The advantages of black lists include focussing the attention of border surveillance systems on high-risk species on the list, and (for the second category) ensuring dangerous incursions are promptly managed. The disadvantages of a black list are that only a small proportion of potential risk species are ever listed and many known and unknown risks remain off-list.

A white list names species that are allowed to be imported. White lists assume all species not on the list are prohibited or must be subject to a formal risk assessement before their importation would be permitted. All is forbidden unless permitted! The advantages of white lists include a more precautionary approach in that all exotic species are considered and risk analyses done as they are intercepted or before someone imports them. The disadvantages are that decision-makers have to know what species are already present in the country and people may be encouraged to illegally import new species rather than subject them to the risk analysis and possible rejection.

Many countries run a dual system. The New Zealand approach is a white list of species already legally in the country such that import of new individuals merely has to meet any condition of keeping (e.g. some might be held only in public zoos), and phytosanitary or disease inspections at the border or in quarantine. All other species are banned unless they pass a rigorous risk assessment paid for by the person wanting to import but conducted by a quasi-judicial authority set up for this purpose. An informal blacklist sits alongside this system so that people know they would be wasting their time applying to import high-risk species or trivial species where the benefit to themselves does not outweigh any potential cost to society.

The Mexican national strategy is taking a black list approach to focus attention on risk species and how they might arrive in Mexico. The list (Table 1) developed by CONABIO records 570 IAS but has (by 2012) performed risk analyses for only 52 species. In the EDRR context a black list should give first priority to IAS that have been found in Mexico but subsequently eradicated, then species that are known problems in other countries with similar climatic matches to Mexico but that are not yet established in Mexico (e.g. Tables 2 and 3 for fish), and lastly on IAS that are already established in Mexico but for which eradication is feasible, and justified[2]. Established species for which eradication (a rapid response) is not possible are outside the EDRR process unless containment is a potential response.

[2] Justification may be based on a prediction of future impacts but decision-makers should, in my opinion, take a precautionary approach and favour eradication (if feasible) even in the absence of hard evidence of adverse impacts in the new place.

3.3 EDRR systems

Early detection and rapid response systems (e.g. Worrall 2002, Crall et al. 2012) have two obvious components each with a timeframe dependent on both the ability of people to work through the process and a biological timeframe determined by the life history of the IAS – some must dealt with very quickly while others will be slow to establish and spread so we can be 'less rapid' in our response.

Detecting incursions by new species requires three management components:

- An appropriate surveillance system - where to search along the biosecurity risk chain or over what area, what with, and how often? Surveillance systems can be active where some agency has responsibility to search the risk areas under some plan, or passive where individuals or groups 'keep an eye out' for IAS. Some element of skill or training is implied.
- The ability to interpret lack of evidence (detection probabilities) so one does not respond inappropriately.
- The technical capacity to identify any plants or animals detected as IAS.

The first two of these components (surveillance and detection probabilities) are based on the simple fact that to be 100% certain that no IAS is present in an area the whole area must be searched everywhere with a system that has perfect detection. Neither total search coverage nor perfect detection are usually possible so the questions managers must answer are:

(a) What is the probability, given realistic surveillance strategies and imperfect detection devices, that no IAS of interest is actually present when none were found?
(b) If this probability is low and the cost of failing to detect an incursion in time to respond effectively or efficiently is high, how much more surveillance should be applied to increase the detection probability commensurate with the risk?

Rapid response against an IAS that has recently arrived in a new area but before the incursion can be classed as an invasion has two management components

- A response to begin removal of the incursion after the IAS is detected.
- A timeframe until this removal is completed.

Clearly, the ability of the IAS to establish and spread sets the actual response timetable – some IAS have to be detected and removed in a matter of days or a few weeks if EDRR is to be successful, while others are unlikely to reproduce and spread for months or years and EDRR can be more leisurely. These timeframes have obvious implications around who has the capacity to react especially in the urgent cases.

The action would ideally entail removal of the individuals in the incursion, but could also include actions to ensure none reproduce, or none spread and establish more widely. Removal of the incursion may be identical strategically and tactically to eradication or extirpation, but generally rapid response follows a different regulatory, funding and accountability process than projects that attempt to eradicate an established population of IAS. Deciding when an incursion becomes an invasion is a key decision point in biosecurity management.

Eradicating such IAS is technically more likely if they are detected early as incursions, but becomes more and more difficult and expensive once they establish and spread.

Eradication is feasible only if some obligate rules can be met (Parkes & Panetta 2009) and any constraints overcome or managed. The rules, in summary, are:

- The rate of removal must exceed the rate at which the target population can increase. To meet this rule all the breeding animals must be at risk ideally within some short timeframe, i.e. the population must be delimited, and control tools and money available.
- There must be no immigration. Logically this risk can never be completely eliminated because the IAS arrived once so may do so again, so some on-going surveillance may be required.
- There must be no net adverse effects – of the control methods or once the IAS is removed.

3.4 EDRR along the biosecurity risk chain

EDRR has to be planned within the wider biosecurity risk chain where other sorts of intervention at potential sources of the IAS, on the different pathways and vectors by which IAS may reach Mexico, and/or post-establishment might be more appropriate (in some cases) than planning EDRR actions. That is EDRR is a reactive strategy – managers look for evidence of an IAS and react only if one is found. In contrast, much biosecurity is proactive where action is taken irrespective of immediate evidence of the presence of IAS – managers fumigate containers, for example, in case an IAS is present.

Some countries are adapting the Hazard Analysis & Critical Control Point (HACCP) planning system to optimise biosecurity interventions, such as reactive EDRR or proactive and precautionary actions, at different points along the source-sink pathway.

Management and EDRR at sources:

IAS may come from anywhere in the world but of course sources with similar climates to Mexico are likely to have the most risky species. The species may be an exotic one and perhaps invasive at the source, or may be native to that place; those already invasive may increase the risk that they will be invasive in Mexico. IAS risks will be proportional to the abundance of the species at the source and aspects of its biology and behaviour that facilitate its propensity to be transported on the vectors from the source to Mexico, and its ability to survive on the vector and indeed in Mexico.

Sources of IAS for Mexico include the all overseas countries that send trade goods, people and vectors to Mexico (with risks being roughly proportional to the volume and type of such pathways), and also of course its land borders with the USA, Belize and Guatemala. The wider biosecurity questions are whether any action against the IAS populations found at these focal departure points or in the countries with land borders is (a) necessary, (b) feasible and (c) will reduce the risk of its arrival and establishment in Mexico?

For legal trade, detection and response at the source is first the responsibility of the source country. Some international and bilateral conventions also require exporting countries to regulate movement of species at the source (Ortiz Monasterio 2013), e.g. a CITES-listed species at source may still be an IAS in a new country – the exotic bird trade is an example.

For products and goods being imported into Mexico the ability to return contaminated imports to the port of origin acts as an incentive for source agencies to manage IAS at source and detect IAS before departure.

Risks of IAS in the internet trade in plants and wildlife might be managed by encouraging suppliers to add cautionary messages in their advertisements. Currently a few suppliers do add such messages where the importing country has clear rules banning the species being offered for sale (e.g. Comité Asesor Nacional sobre Especies Invasoras 2010) but a survey of Mexico's blacklist species that are offered on the web and targeting these suppliers with a caution should be possible. How much risk would be mitigated is unclear. Nevertheless, there is only so much an importing country can rely on biosecurity at source countries and the ultimate responsibility for biosecurity falls on the importing country.

An EDRR approach to management at sources is to create 'alert' lists of IAS known to be present at the source and not in Mexico to direct actions at the source (where possible) or to pre-warn sureveillance systems further along the risk chain – the status and spread of *Cactoblastis cactorum* in the region is an obvious example of interest to Mexico's alert system.

Management and EDRR on pathways:

The process by which IAS can be transported to or arrive in Mexico might be thought of as pathways, and these can be intentional or accidental, anthropogenic or natural. Some common pathways relevant to Mexican biosecurity include personal baggage of residents and visitors, cargo and packaging material, construction materials, ballast water on ships, mail, the pet and horticultural trade, aquaculture, fresh food, and fishing equipment. Natural spread of species across land borders or naturally by flying or being blown in on hurricanes might also be thought of as pathways.

Mexican authorities have some ability to proactively manage IAS along some pathways pre-border either directly via import restrictions on some species, by encouraging various phytosanitary requirements imposed on importers (see the forest product requirements in section 5.3), or by enforcement of de-rat certification on ships. Other pathways are not so amenable to proactive management of IAS. Ballast water, for example, cannot be managed by an EDRR system of surveilance and reaction but requires a precautionary approach, and this is not easily managed to reduce the risk from marine IAS (see the discussion in Mendoza et al. in press).

Management at the end-point of pathways is by border control and quarantine and is discussed below.

EDRR on pathways usually depends on the compliance of the people involved with international and national laws, regulations, and agreements. The agencies of the Mexican government may enforce or encourage such compliance but direct detection or response activities on the pathway itself are often not possible other than at the end point of the pathway at the border in Mexico.

Management and EDRR on vectors:

Vectors can be abiotic such as land transport, aircraft or ships or biotic when an IAS such as a disease, fungi or invertebrate arrives with an importation of a plant or animal. Natural phenomena such as hurricanes may also be thought of as vectors.

Management can be either proactive or reactive (EDRR) on some vectors, e.g. ships may maintain rodent bait stations as permanent fixtures or only deploy them if sign of pest are detected. However, managing IAS that are detected on an importation of a plant or animal or blow in with hurricanes requires the reactive approach of EDRR – at the border inspection for the former and as post-border surveillance for the latter.

Management and EDRR at the border:

Responsibilities for the Mexican biosecurity system fall across many government agencies (Fig. 1). SAGARPA and its agencies (SENASICA for agriculture, CONAPESCA (aquaculture), are responsible for managing productive sectors. SEMARNAT and its agencies (CONANP for national parks, PROFEPA for environmental law enforcement including surveillance at the border, CONAFOR for forestry) are responsible for environmental sectors.

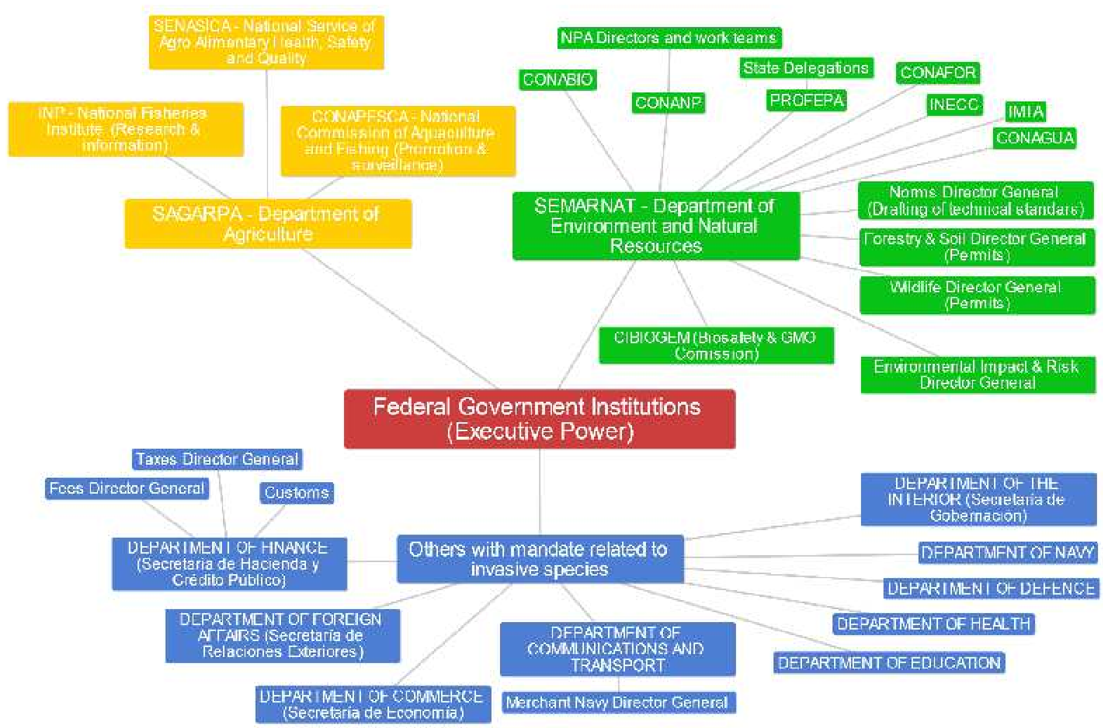

Figure 1. Relationships between Mexican agencies involved with national biosecurity (after A. Ortiz 2013).

PROFEPA's goal is to reduce the risk of introduction of IAS associated with the importation of goods that are regulated by SEMARNAT. They have 90 permanent inspectors, in 72 offices around Mexico with an annual budget for inspection activities of US$826,000. They inspect imported goods for IAS at the border – at 57 points where IAS incursions are possible. Inspectors have the power to return any contaminated goods to the source country, but once past the inspection they cannot act further unless an IAS that has escaped early detection is actually seen to be causing damage.

Management and EDRR post-border

Some IAS get past the border and arrive in Mexico (an incursion) that may or may not establish and may or may not spread and may or may not become a problem to the economy, biodiversity or human health.

There appears to be a gap in capacity between inspection at the border and detection of incursions in that agencies have no mandate to check products or species once they pass the border. They must wait until an incursion is reported before they act. However, once detected Mexico has sophisticated EDRR processes for pests and diseases of production assets but less so for IAS that potentially affect biodiversity values.

SAGARPA has a more proactive post-border mandate than PROFEPA. Through SENISICA, it manages the national phytosanitary and animal disease sureveillance and reaction programs within Mexico. The agency has world-class processes to detect, report, diagnose and respond to diseases and pests of agriculture (Exotic and Emerging Diseases National Information System (SINEXE)) and regulated pests (National Emergency Dispositive Against Regulated Pests in Mexico (NED)), reinforced by some international agreements to manage the risks of some very high-cost IAS such as foot-and-mouth disease.

SINEXE began in 2009 (Fig. 2) and has a current annual budget of US$24.7 million. The system relies on trained field staff and private veterinarians to detect possible new diseases in livestock. They can capture these clinical indications electronically and take samples for diagnosis. The clinical symptoms can be sent by smartphone or laptop computer (with a case number and barcode) to one or more of 21 laboratories in Mexico for a confirmed diagnosis. The time from field detection to diagnosis is recorded and the diagnoses are provided daily to SAGARPA for rapid response as required. This system allows some chance of early detection as farmers and their veterinary support report potential cases, but ensures a rapid diagnosis and rapid response.

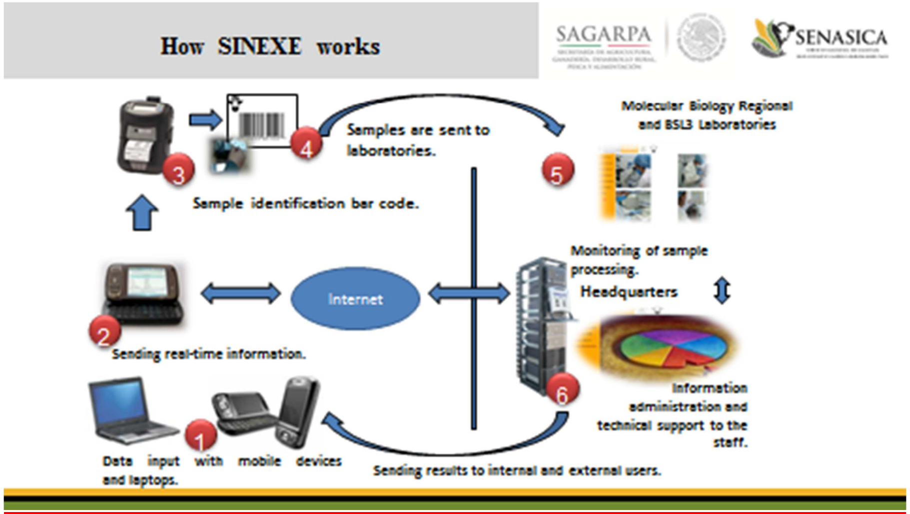

Figure 2. Graphic of the SINEXE process

It will be interesting to measure not only the success rates of SINEXE and NED but also where they fail to detect and report IAS in time to allow a rapid response – essentially in time to eradicate the incursion.

In 2012, 31 502 cases were investigated including some with biodiversity implications such as Parapoxvirus that might infect native ungulates, avian diseases such as West Nile Virus, and fish diseases.

3.5 National investment on biosecurity

It is not clear how much Mexico spends in total on biosecurity, or whether this is sufficient. Component budgets for PROFEPA and SINEXE total around US$25 million but that spent by other agencies is not known to me.

To put the sum into context, New Zealand (an island nation of 27,000 km^2 and 4.5 million people) spends US$200 million each year on biosecurity funded by government agencies, plus an unknown amount by private landowners. About 36% is spent on border security and post-border management in productive sectors by central government (i.e. about US$72 million compared with about US$25 million for similar functions in Mexico), 31% on pests and weeds affecting biodiversity on the reserved conservation estate, 20% by local government mostly on private land, and 13% by joint government and private agencies on management of wildlife vectors of bovine tuberculosis.

4 Ornamental aquarium and aquaculture trades

4.1 Aquarium trade

The ‘aquarium trade’ is largely catering for people who keep ‘ornamental’ fish in home aquaria or sometimes in larger public aquaria. Data on the aquarium trade is sometimes inconsistent, but the industry is clearly very large. The international list of known IAS from the aquarium trade is long (n = 904 for freshwater fish alone according to Froese and Pauly (2002) but with many more invertebrates, e.g. apple snails (*Pomacea canaliculata*) and plants (*Hydrilla verticillata*). The USA alone imported 121 species of non-native fish into its aquarium trade between 2000 and 2004 totalling nearly 1 000 000 000 individual fish of which only 2% were identified to species level (Jenkins et al. 2007). Similarly, Mendoza Alfaro et al. (2012) noted that up to 1000 freshwater fish species and about 1 billion individuals are sold in the ornamental fish trade around the world. An industry worth US$15 billion!

The Mexican aquarium trade consists of local commercial breeders and those who catch wild Mexican species who supply the Mexican market, importers who bring in wild or captive bred animals from other countries, retailers who sell the fish, afficionados who trade or swap specimens among themselves, a large number of Mexicans who keep fish in home aquaria as pets or ornaments, and fewer large public aquaria where fish are kept for public display. Ramírez-Martínez et al. (2010) reported in Mendoza et al. (in press) that the ornamental fish industry in Mexico sells about 43 million fish each year, with about half bred in Mexico and half imported. The whole industry employs 41,000 people with an annual income of over US$160 million (Mendoza Alfaro et al. 2012).

Freshwater species are more common than marine species in the ornamental trade. In the 1980s in Mexico 55 exotic fish species were registered as being in the aquarium trade but by 2004 there were 118 registered species (Mendoza Alfaro et al. 2012). The 20 most common fish in the ornamental trade are listed in Table 2.

Table 2. Most common ornamental fish produced in the commercial trade in Mexico (after Ramírez Martínez et al. (2012).

Fish species	**Known to also be in the wild in Mexico (c.f. Appendix 2)**	**Known to be invasive elsewhere and a risk in Mexico (c.f. Appendix 1)**
Carassius auratus (Goldfish)	Yes	
Cyprinus carpio (Common carp)	Yes	
Poecilia reticulata (Guppy)	Yes	
Poecilia latipinna (Common molly)	No	No
Poecilia velifera (Yucatan molly)	Yes	
Pterophyllum scalare (Angel fish)	No	Yes
Trichogaster trichopterus (Threespot Gourami)	No	Yes
Xiphophorus maculatus (Platy)	No	No
Brachydanio rerio (Zebra danio)	No	No
Xiphophorus hellerii (Green swordtail)	Yes	
Gymnocorybus ternetzi (Black tetra)	No	Yes
Melanochromis johanni (Bluegray mbuna)	No	Yes
Hemigrammus caudovittatus (Buenos AiresTetra)	No	No
Haplochromis fenestratus (Fenestratus cichlid)	No	No
Astronotus ocellatus (Oscar)	No	Yes
Capoeta (Puntius) titteya (Cherry barb)	No	No
Trichogaster (Colisa) lalia (Dwarf gourami)	No	Yes
Neolamprolagus leleupi (Lemon cichlid)	No	No
Hypostomus plecostomas (Suckermouth catfish)	Yes	

Betta splendens (Siamese fighting fish)	No	Yes

Bonilla-Barbosa & Araúz (in press) listed 58 (16 exotic and 42 translocated natives) species of freshwater aquatic exotic plants present in the wild in Mexico, of which eight have been sold in the aquarium trade (Table 3). Four species of freshwater molluscs are invasive in Mexico (Naranjo-García in press), of which three (a translocated native apple snail (*Pomacea flagellata*) and two exotic species (*Tarebia granifera* and *Melanoides tuberculata*) escaped from the aquarium trade and one (the clam *Corbicula fluminea*) was introduced as a food source. A few reptiles, such as the red eared slider turtles (*Trachemys scripta elegans*), are also traded.

Table 3. Species of aquatic plants known to be weeds offered for sale in the internet trade (after Wersal & Madsen 2012).

Species (* translocated native species)	**Present in the wild in Mexico**
Alligator weed (*Althernanthera philoxeroides*)	Yes
Seaweed (*Caulerpa taxifolia*)	Yes
Coontail (*Ceratophyllum demersum*)*	Yes
Didymo (*Didymospenia geminata*)	No
Water hyacinth (*Eichhornia crassipes*)	Yes
Hydrilla (*Hydrilla verticillata*)	Yes
Rice grass (*Leersia hexandra*)	No
Parrot feather (*Myriophyllum aquaticum*)	Yes
Watermilfoil (*Myriophyllum spicatum*)	?
Reed (*Phragmites australis*)*	Yes
Water lettuce (*Pistia stratiodes*)*	Yes

Commercial fish farms:

Currently, 61 varieties of 19 species are bred in Mexico in over 250 fish farms (mostly in Morelos state) with an annual and growing income of about US$65 million (Ramírez Martínez et al. 2012).

A survey of 42 ornamental fish farms between 2005 and 2008 showed 50% used water from agricultural irrigation canals and most obtained their breeding stock from retailers or other farms. Farms changed between 5 – 10% of their water each day and presumably the discharged water went back into the source – along with any fish or their eggs that were not filtered out (Ramírez Martínez et al. 2012). I have seen very expensive filtering systems in Queensland, Australia that were attempting to keep tilapia out of new water catchments being irrigated from infected rivers. They eventually failed.

Mendoza Alfaro et al. (2012) note the lack of legal instruments available in Mexico which, along with 'fierce competition' between and among domestic farmers, importers, wholesalers and retailers, suggests limited opportunities to regulate the risks that some will become IAS.

Commercial importers:

A large number of taxa (700 varieties of 117 families) are also imported – 18 million fish in 2006. Many come from tropical South America and from Asia via the USA. Those imported from South America (mostly the Amazon Basin) are wild-caught, while most from Asia via the USA are captive-bred (Mendoza Alfaro et al. 2012) (Table 4).

Table 4. Numbers of the most common exotic fish families and species imported for the aquarium trade in Mexico (after Mendoza Alfaro et al. 2012).

Family	No. of species	No. of individuals
Cichlidae	107	161,276
Characiidae	64	1,187,788
Cyprinidae	27	1,092,506
Callichthyidae	24	130,385
Loricaridae	20	102,743
Conaitidae	15	?
Aplocheilidae	13	?
Anabantidae	12	?
Pimelodidae	11	?
Osporonemidae	?	689,776
Poeciliidae	?	456,563
Ambassidae	?	133,003
Pangasiidae	?	118,739

Retail trade:

During the 1970s there were only 100 retailers of ornamental fish in Mexico but beginning in the 1980s the restrictions on importing fish were relaxed and some aquaculture farms in Mexico converted from farming tilapias and prawns to breeding ornamental fish that are sold in perhaps 20,000 aquarium stores (Mendoza Alfaro et al. 2012).

Home aquaria:

Ornamental fish are popular in Mexico, particularly in the large cities where people do not have the space to keep other pets (Mendoza Alfaro et al. 2012).

4.2 Aquaculture trade

Exotic species managed for food or sport are sometimes also held within the ornamental fish trade, but those primarily managed for food for people are dominated by tilapia species held in reservoirs or canals, while those for sport are generally bass and salmonids with some smaller species, such as shads, cultivated as food for these.

4.3 Impacts of escapes from aquarium and aquaculture trades

Exotic animals and plants escaping from the trades may adversely affect both native plants and animals and commercial fisheries. As an example of impacts to native species a long-term study in one river in central Mexico showed a decline in native species abundance of 11 – 30% per decade as exotic species increased by 9 – 20% per decade. *Xiphophorus variatus* (a translocated native platy common in the ornamental fish trade) and *Micropterus salmoides* (a translocated bass native to northern Mexico and the USA released as a game fish) were the most common exotic fish in the river (Mercado-Silva et al. 2006).

Introducing exotic fish has had a cascade of effects in one commercial fishery in Mexico. The large (40, 000 ha) reservoir known as El Infiernillo was formed in 1963 and had a fishery based on native species. However, the introduction of four tilapia species and four carp species largely replaced the native fish but allowed a thriving industry supporting 119 communities and 45,000 people. In 1987, for example, nearly 19,000 tons of tilapia were caught. An important commercial benefit of the invasive tilapias and carp, but an adverse outcome for the native fish. Armored catfish or plecos were introduced into a dam upstream of the reservoir to control algae but in 2004 escaped downsteam into El Infiernillo. There was some evidence that the tilapia fishery was in decline into this century, but after the arrival of the plecos the catch of tilapia declined by about threefold with severe consequences for the local economy (Mendoza Alfaro et al. 2009).

4.4 Risks from exotic fish in Mexico

These ‘trades’ present different risks of establishment. Aquaculture species are deliberately imported and released into natural waterways, while aquarium species establish in the wild both as escapes from natural waterways where they are cultivated and when owners carelessly empty aquaria of unwanted fish. Sports fish that are IAS are also distributed by misguided fishing enthusiasts.

The ‘lists’ approach to risk analysis would divide species in the trades into three categories.

(a) Species known to be invasive elsewhere in the world in similar habitats to those in Mexico, but not present in the aquaria or aquaculture trade or in the wild in Mexico (FishBase at www.fishbase.org) (Appendix 1 and Table 5).

(b) Species not present in the wild in Mexico, but held in aquaria or in captivity in aquaculture in Mexico (e.g. Mendoza Alfaro et al. 2013).

(c) Species known to be present in the wild in Mexico (e.g. Contreras-Balderas 1999; Mendoza Alfaro in press), or known in the wild in protected areas in Mexico (García Martínez et al. in press) (Appendix 2).

Species established elsewhere but with suitable habitat in Mexico

FishBase records 129 fish species known to have established populations outside their natural range that are deemed likely to be able to establish in Mexican waters should they be released. Most (75%) are freshwater species, only 9% are truly marine species, and the rest are species that spend part of their lives in both fresh and salt water (Appendix 1). Six of these species are known IAS and listed in the ISSG database.

Marine fish appear less able to establish in new areas than freshwater ones. Froese & Pauly (2002) recorded 1145 successful fish introductions of which only 241 were marine species with 94 of these being tropical species. In Florida, Semmens et al. (2004) recorded 14 exotic marine fishes that have originated from the local USA aquarium trade (Table 5), of which one (the lion fish) is now known to be in Mexican waters and, it can be assumed, the others could reach Mexico unaided by humans[3].

Non-fish marine species known to be invasive elsewhere in the world include the alga *Caulerpa taxifolia*. A sterile aquarium variant of this escaped into the Mediterranean and now carpets vast areas of that sea. Populations of this variant have been found in southern California, and fortunately detected in time to allow eradication to succeed (Anderson 2005).

Marine species may reach Mexico directly as escapees from Mexican aquaria or naturally from known risk areas such as Florida – where biosecurity is, to say the least, notoriously ineffective (Simberloff et al. 1997).

Table 5. Exotic marine fish found in Florida as suspected escapes or liberations from the aquarium trade (after Semmens et al. 2004).

Fish recorded in Florida	**Found in Mexican waters**	**Native range**
Sohal surgeonfish (*Acanthurus sohal*)		Red Sea
Racoon butterfly fish (*Chaeotodon lunula*)		Indo-Pacific
Panther grouper (*Chromileptes altivelis*)	Yes	West Pacific
Orangespine unicorn (*Naso lituratus*)	Yes	Indo-Pacific
Orbicular batfish (*Platax orbicularis*)	Yes	Indo-Pacific
Blue ringed angelfish (*Pomacanthus annularis*)		Indo-Pacific
Arabian angelfish *(Pomacanthus asfur*)		East Africa
Emperor angelfish (*Pomacanthus imperator*)		Indo-Pacific
Yellowbar angelfish (*Pomacanthus maculosus*)		North Indian
Semicircle angelfish (*Pomacanthus semicirculatus*)		Indo-W. Pacific
Lionfish (*Pterois volitans*)	Yes	Tropical Pacific
Moorish idol (*Zanclus cornutus*)	Native to S. Gulf of California	Indo-Pacific
Sailfin tang (*Zebrasoma desjardinii*)		Indian
Yellow tang (*Zebrasoma flavescens*)		West Pacific

Species held in aquaria in Mexico but not present in the wild:

The key gap from any risk analysis of the aquarium and pet fish trade is a list of fish and other species held in the trade within Mexico but not yet found in the wild. Mendoza Alfaro et al. (2012) list the number of species commonly imported and suggest at 293 species/taxa of fish are currently present in the aquarium trade in Mexico, and 67 of these are known to exist in the wild. This leaves over 200 species held in the ornamental aquarium trade that are not yet in the wild in Mexico, which species is not recorded in the literature.

Species known to be present in the wild in Mexico:

Appendix 2 lists 120 species of fish known to be present in the wild in Mexico. Most (n = 93) are non-native while some (n= 27) are translocated Mexican species. Thirty-six are exotic incursions from the ornamental trade, 34 are native translocations from the ornamental trade, 31 are deliberate releases of food or sport species, 2 were deliberate releases of exotic

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[3] 12 of these Florida fish species are not listed in the FishBase database (Table 3)

threatened species from the USA to extend their range (the tui and arroyo chubs), 7 were of exotic species invading Mexican waters (e.g. the lion fish), and 2 appear to have arrived with ballast water or as eggs on ships' hulls. Twenty one species are listed on the ISSG database.

4.5 Management of IAS from the ornamental and aquaculture trades

Eradicating aquatic IAS, once they establish, even in enclosed waters is exceedingly difficult so a good rule is to intervene early in the biosecurity risk chain, i.e. do not import the species or, if it is imported, do not let it escape is the best advice! The risks of an incursion differ depending on whether the species is a freshwater or marine species. For example, marine species held in aquaria or farmed in aquaculture are a risk to Mexican seas irrespective of whether it is Mexico or a neighbouring country that allows them to be kept. While freshwater species are a risk primarily only if kept within Mexico – with lesser risks when freshwater IAS invade the Rio Grande from USA or the Rio Usumacinta from Guatemala.

Eradication of aquatic species in small enclosed waters or when detected early enough in rivers is sometimes possible. Nico & Walsh (2011) surveyed some attempts to eradicate exotic fish (mostly tilapias and *Gambusia*) from freshwater sites on Pacific islands. Most of these attempts that succeeded (8 of 16 species/sites) used the fish toxin rotenone – which is not species-specific and is only feasible in small enclosed waters. Reviews of the common piscecide rotenone and alternatives have been made by Rayner & Creese (2006) and Clearwater et al. (2008), but again are practical only for small water bodies.

Trapping, netting, and electrofishing are possible method to attempt eradication, but again are all scale-restricted. For example, the jewel cichlid (*Hemichromis guttatus*) was apparently eradicated from one area of Mexico. This small enclosed pond (only 28 m across and 0.8 m deep) was trapped with 25 standard minnow traps for 5 – 10 h for 20 sessions over 4 years when 19,071 cichlids were removed. The last three sessions caught no cichlids and eradication was claimed (Lazano-Vilano et al. 2006). Validating success is always a problem for eradication projects but analytical methods are being developed to give probabilities that none found equals none left (e.g. Ramsey et al. 2009) rather than simple judgements based on the absence of evidence as in the above case.

Sustained control options to reduce IAS fish is possible. One such option is to use biocontrol (e.g. using viral agents such as *Rhabdovirus carpio* to manage carp) or various genetic approaches (e.g. introduction of daughterless or fatality genes into the target population) are still experimental and unproven in the wild (Roberts & Tilzey 1996; Thresher 2008). Another option mooted is to commercially exploit the IAS as is suggested for the lion fish – although whether this affects the population as a pest is unknown.

Biosecurity solutions for risk species not yet in Mexico:

For all species (marine and freshwater) not already in Mexico that might be a risk if they appear in Mexican waters from the aquarium or aquaculture trade the best solution is the blacklist – ban importation of those that are known problems elsewhere and likely, after a detailed risk analysis, to become invasive in Mexico. The blacklist would need to have some legal status to allow regulatory agencies to use it for this purpose.

Border control of aquatic species can present diagnostic problems. For example, fish imported as eggs or hatchlings are difficult to identify and might be claimed to be a permitted species but in fact one on the blacklist. DNA barcoding offers solutions to this identity problem (e.g. Collins et al. 2012), i.e. is blacklisted "species x" present, or which species of pleco is this?

Biosecurity solutions to risk species in 'captivity' in Mexico:

Given the scale of the ornamental aquarium trade in Mexico it may be possible to limit new risk species from entering it as above, but trying to remove high risk species already within the system will be difficult without a strict inspection and regulation process plus some education to achieve voluntary risk reduction. This may be difficult as the industry lacks, according to Mendoza Alfaro et al. (2012), a coherent internal organisation to represent the commercial parts of the trade, and no efficient regulatory instruments.

Attempts at regulation (with its necessary inspection and complience) may make matters worse as owners with blacklisted fish release them into the wild rather than surrender them to authorities. Voluntary behaviour changes may be a more productive approach. Some countries have developed voluntary codes of practice for trade in known IAS. For example, the horticultural trade in New Zealand has agreed not to sell a list of plants known to be major IAS.

Biosecurity solutions for species already in the wild:

The management options to deal with aquatic species that are already pests are limited largely by the constraints and costs of the tools available to manage them.

Conclusion:

There is limited scope to use EDRR systems in the management of aquatic species in the wild. This is because detecting incursions is not easy and the technical capacity to manage (let alone eradicate) even incipient incursions (let alone established populations) is limited. Therefore, management of IAS risks from the trade in species in the aquarium and aquaculture industries has to focus on restricting entry at the border of potential IAS. Managing the exotic species already in Mexico in the aquarium and aquaculture industries to reduce risks that escaping or liberated animals will establish pest populations will require active collaboration of the industry stakeholders to, for example, restrict places where such species are cultivated, farmed or held.

5 Trade in wildlife

Since 1995, PROFEPA inspected 398,897 importations of regulated wildlife. There is apparently a very large trade in wildlife (both legal and illegal) in Mexico, both using wild-caught and captive bred native species and using imported species. For example, a survey of 179 owners of primates in Mexico City alone showed that 3 native and 9 exotic primates were held as pets and mostly sourced in a large local pet market (Duarte-Quiroga & Estrada 2003).

It appears to be rather difficult for exotic terrestrial vertebrates to establish in the wild in Mexico (Table 1) despite the large potential source of such species in the wildlife and pet trade.

As a case study Cantú-Guzmán et al. (2007) analysed the trade in parrots in Mexico. They showed that between 1995 and 2005 Mexicans imported 180 species of parrots mostly for commercial sale as pets (Table 6).

Table 6. Ten main exotic parrot species imported into Mexico, 1995 – 2005.

Species	**No. imported**	**Wild in other countries**	**Wild in Mexico**
Peach-faced lovebird (*Agapornis roseicollis*)	32 319	Yes	No
African ring-neck parakeet (*Psittacula krameri*)	8 145	Yes	No
Yellow-collared lovebird (*Agapornis personatus*)	5 754	Yes	No
Eastern rosella (*Platycercus eximus*)	5 415	Yes	No
Senegal parrot (*Poicephalus senegalus*)	4 860		No
Fischers lovebird (*Agapornis fischeri*)	3 910		No
African grey parrot (*Psittacus erithacus*)	3 782		No
Monk parrot (*Myiopsitta monachus*)	2 931	Yes	Yes
Burrowing parrot (*Cyanoliseus patagonus*)	2 820		No
Red rumped parrot (*Psephotus haematonotus*)	1 864		No

Only one of these 180 species of parrot has apparently established a wild population – the monk parrot as a recent illegal release in Guerrero Negro, Baja California. While of the eight other introduced birds species present in Mexico, only the doves (*Streptopelia decaoata* and *S. chinensis*) and munia (*Lonchura malacca*) are likely to have established from cage-bird escapes or releases.

Biosecurity and EDRR solutions:

On the positive side it appears few of the hundreds of wildlife species being brought into Mexico in the pet or productive sector have established wild populations. On the negative side there remains a large risk from at least some of these species, with added uncertainty around the lack of knowledge (or at least my lack of knowledge) about what species are actually present in Mexico.

A survey of what species are in Mexico is not a trivial exercise. A list of all wildlife legally imported, i.e. with CITES or animal health certificates at the border would be a first step, but the real risk is understanding how and where they are kept in the country. A partial list could be developed but it would contain many gaps as some species imported would not survive, and I assume there is some illegal trade. The proposed blacklist of species would at least discourage or halt some legal attempts at importing wildlife, but may increase illegal attempts as those people who once followed the rules wanted to import black-listed species.

The only practical solutions are:

- To have a system where incursions from escaped or release wildlife are reported and managed. The proposed eradication of the parrot population at Guerrero Negro is a case in point (Parkes 2013)

- To put conditions on where some species may be held (i.e. away from sensitive biodiversity areas), or who and how they may be kept (e.g. only in public display facilities with appropriate conditons to ensure animals do not escape).

6 Trade in forest products

Since 2006, PROFEPA has inspected 387,740 wood pallets and packaging, over 5 million Christmas trees, and over 1 million other forest products. Since 1995, they detected 6719 exotic species of which 1665 were identified as quarantine pests that required the shipment of the infested good to be refused entry to Mexico.

In 2010, PROFEPA performed 62 016 inspections of forest products (Fig. 1) at the border and detected 145 exotic species of which only 26 (18%) were considered a quarantine risk. Most exotic detections orginated in products from the USA but only 5% were of quarantine interest c.f. 11 of 16 imports from India 100% (of few imports) from Spain and Malaysia (Fig. 2). Beetles form about 65% of the exotic species detected (Fig. 3).

The annual importation of over 1 million conifers (*Pseudotsuga*, *Pinus* and *Abies*) from Oregon and Canada since 2009 presents biosecurity risks (Fig. 4). The trade has some costs for Mexican tree growers but has national biodiversity benefits as it limits the exploitation of natural forests in Mexico. All containers with trees are inspected by PROFEPA's officers at the border and to date about 14 pest IAS with the potential to establish in Mexico have been detected. Contaminated containers are returned to the source at the importers' expense – which reinforces their efforts to ensure the containers leave the source port in a clean state. In 2012, about 0.2% of the million trees imported were sent back.

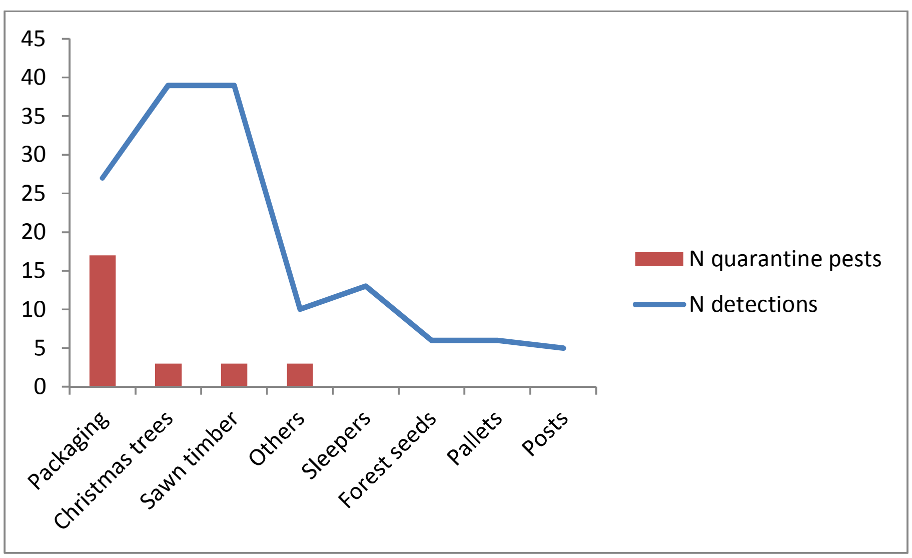

Figure 1. Number of exotic species (blue line) and number of species of quarantine concern (bars) detected in seven forest products imported into Mexico in 2010 (source PROFEPA).

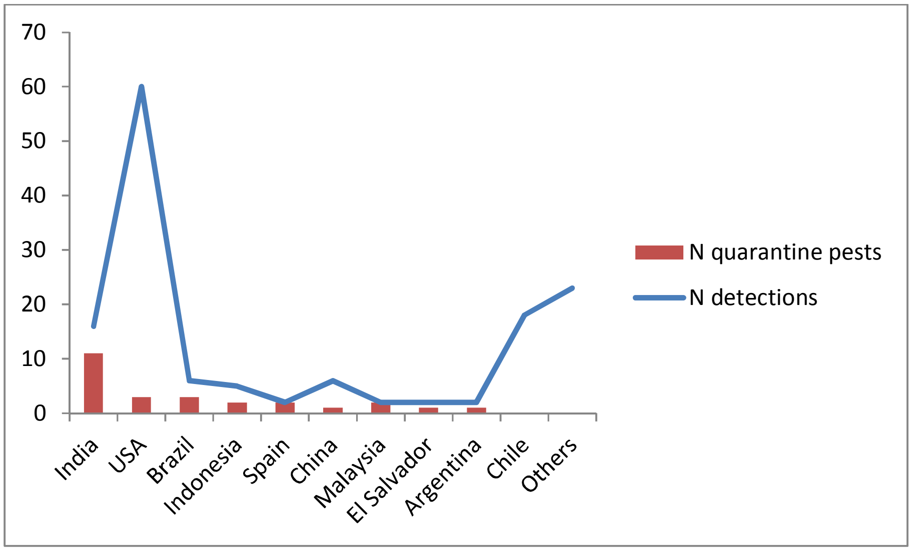

Figure 2. Exporting countries with exotic species detected at the Mexican border and the number of these of quarantine concern (source PROFEPA).

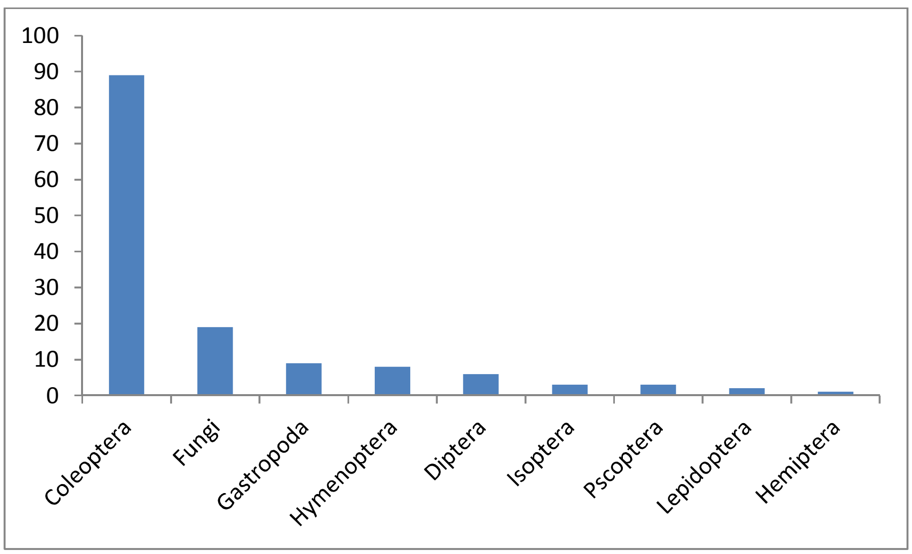

Figure 3. Main taxa of exotic species detected in timber products at the border in Mexico (source PRFEPA).

Biosecurity and EDRR solutions:

The general process of applying the international standards for phytosanitary measures for importing wood and forest products appear to be working reasonably well, judging by the high risk case study above. However, like all border biosecurity systems, more investment in priority areas would reduce risks. PROFEPA noted the need for increased training of their inspectors to be aware of the risk species on the final blacklist, in specialised skills in detection methods and systems, and in the identification of suspect organisms and the process required to validate uncertain detections.

7 Recommendations

It is axiomatic that biosecurity risks can be reduced by investing more in management along the risk chain and/or by focussing on a wider range of species or pathways. The Mexican government has two general options to increase its investment on management of IAS affecting biodiversity values, i.e. those with a non-market value for which the applicability of marginal cost/benefit analyses is debateable. It could allocate some set increase in funding and develop systems to maximise the benefits by prioritising actions (benefit maximisation). Alternatively it could prioritise a pipeline of key projects and fund this list of desired projects most efficiently (cost minimisation).

The question for the GEF project is where to inject its budget of around US$5 million over four years to leverage Mexico's input for optimal effect, i.e. a benefit maximization approach is required in the short-term.

The options are to invest most in one large project aimed at creating a step-change in national capacity using EDRR as the pilot process, or to invest in several smaller projects that would improve weak components of the current biosecurity system (see Parkes 2013 and some suggestions below), or the former and fewer of the latter.

7.1 Recomendations for the FSP

Step-change project:

The main weakness in national ability to manage IAS affecting biodiversity in Mexico is the lack of capacity to deliver action against incursions detected post-border (and established IAS) even on land reserved for biodiversity protection. I recommend developing such capacity in EDRR as a first step towards developing wider capacity to eradicate or control established pests.

Mexico has excellent EDRR systems to detect and manage incursions (diseases and pests of livestock and agricultural plants) that impact on productive systems. While successful EDRR responses against such species has benefits for IAS that also affect native biodiversity there is no such sophisitication in detecting, mapping and planning for the management of IAS that impact only or primarily on native ecosystems and biodiversity.

The FSP should invest in developing the three components of EDRR for biodiversity protection. These components are the capacity to detect and report dispersed and unpredictable incursions post-border, the capacity to plan a response, and the capacity to deliver such a response, i.e. two components are process while the last is delivery of action. A way forward would be to invest first in the planning component and allow it to promote the more dispersed detection and response components.

As a first step the ‘early detection’ information collected in SINEXE and NED should be shared with the environmental agencies when the IAS detected has the potential to impact on biodiversity values. This would require one position in a SEMARNAT agency (CONABIO?) to be dedicated to liaising with the SAGARPA agencies and collating data on incursions with the potential to affect biodiversity. The surveillance components of SINEXE and NED should also be encouraged to report new species found but not necessarily of interest as agents of disease or threats to production.

Within SEMARNAT agencies the FSP should develop a planning or coordination capacity to receive the information collected above and plan a response. This group would need to have skills in IAS management inclusing access to the technical data management skills currently within SAGARPA. The group could be as small as two or three people with appropriate support and be based in an agency with the mandate to sequester funds for a response. Costs would be for four FTEs, i.e., about US$80,000 per year. This should be formed as soon as possible.

The first tasks of this foundation group should be to develop/promote:

1. A surveillance and reporting cadre of CONANP park managers, PROFEPA inspectors, university researchers, NGO staff and interested local people to replicate the farmers, veterinarians and others who find and report diseases and pests in productive sectors. Investing in training this reporting cadre, especially within CONANP and PROFEPA, will be required. The FSP should fund a position (or positions within each agency) to develop the standard operating procedures, and organise the training systems required to develop the government detection cadres. These cadres would then be responsible for extending their local capacity (e.g. particularly with PNA stakeholders) to detect and report incursions – a process extending beyond the FSP. The pilot studies suggested in the site-based projects could be used to test this system.

2. A process to replicate, with appropriate modifications, the technological expertise used to design the EDRR surveillance and reporting systems used by SINEXE and NED. This could be done by secondment of a person who developed the software in SINEXE or NED.

3. A diagnostic service to validate the report and a planning service to prepare a rapid response directive. The diagnostic service will need to be dispersed according to where the taxonomic expertise exists – often within universities and research agencies.

4. Capacity to actually respond. The dilemma government faces is that to justify a permanent capacity just to respond to new incursions (of IAS affecting bidoversity) there would have to be an ongoing pipeline of events – in essence failures of border security. The solution is to nest this rapid response capacity within a wider capacity to manage IAS affecting biodiversity post-border.

5. For PNAs this investment should be through CONANP. This agency needs to develop the skills in prioritising and planning national IAS management. A small group with expertise at this level should be developed to select projects and promote action against IAS in PNAs. The delivery of selected projects requires investment at

the local or park level and can be deployed to suit local circumstances – with local communities, contracted staff or park staff as best suited to the particular project.

Specific projects:

There are many border biosecurity processes that could be strengthened.

Black lists. Completion of CONABIO's blacklist of species not currently in Mexico, particularly in the ornamental or commercial fish trade would identify gaps in current border surveillance processes. For example, this list can be used in an attempt to restrict the importation of new aquatic species with appropriate publicity to the aquarium and aquaculture trade and can alert border regulatory authorities that some new species should not be approved for import or not approved for translocation within Mexico. This should be relatively simple for species used in aquaculture for food or sport, but given the unregulated and competitive nature of the ornamental fish trade I suspect more complex responses (legal, regulatory and educational) will be prerequisites to justify any future investment in EDRR processes.

Mandating the SEMARNAT agencies to develop the step-change program above would be facilitated by development of blacklists. A blacklist promotes a more precautionary approach to rapid response, i.e. SEMARNAT agencies should not have to wait until an IAS incursion is actually observed to be causing damage before acting to remove or manage it.

Agencies have no mandate or ability to check or sample imported products or species once they have passed the border to see if they have missed IAS at the border or to identify the fate of species legally imported. A change in the law or policy would be required.

Finally, public awareness of the risks and costs of IAS to biodiversity appears to be low in Mexico. As a first step in raising this awareness the importers of wildlife (in particular) and any civil society groups involved in the industry could be targetted to raise the consequences of the blacklist and its associated risk assessments.

7.2 Monitoring outcomes as indicators for the FSP

Success might be measured by monitoring the recommended process and/or by measuring the consequences on managing the IAS themselves.

Formation of the coordinating group would be the primary indicator of success of the GEF investment. Secondary indicators for this group would be success in their terms of reference - modification of the SAGARPA EDRR systems for IAS of biodiversity, identification of and formal memoranda of understanding with agencies capable of confirming diagnoses, and development of capacity to manage IAS within CONANP.

Tertiary indicators of success would be on the number of IAS affecting biodiversity detected and removed, and its reciprocal, the not detected in time for a rapid response or detected but not removed. It is of course unclear a priori how many such invursions will be detecetd over the period of the FSP, but if the project uses some current incipient incursions (see Parkes & Williams 2013) as models to test the new systems the outcomes of these could be used as indicators of success.

7.3 Recomendations for after the FSP

Biosecurity along risk pathways is much wider than EDRR. CONABIO should promote a HACCP analysis of the optimal intervention points and legal or regulatory changes for reducing risks from some key species in the productive sector that might affect biodiversity values if they establish outside their intended place. This would require cross-sectoral inputs from government agencies and the relevant industry.

The development of EDRR capacity in IAS for biodiversity protection should lead to better management at the border by better identification of problem species that were not restricted at the border, and of established IAS that require eradication or sustained control.

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10 Appendices

Appendix 1 Fish species in the aquaculture and aquarium trade with escaped populations elsewhere in the world that may establish in Mexico (after FishBase accessed May 2013). F = freshwater, E = estuarine or brackish, M = marine. 1 = ornamental trade, 3 = aquaculture food , 3 = sport or bait fish.

Species	**ISSG listed**	**Habitat**	**In trade in Mexico**	**1**	**3**	**4**
Platinum acara (*Aequidens latifrons*)		F		+		
Blue acara (*Aequidens pulcher*)		F		+		
Red devil (*Amphilophus labiatus*)		F		+		
Climbing perch (*Anabas testudineus*)		F, E		+		
Hart's rivulus (*Anablepsoides hartii*)		F		+		
Japanese eel (*Anguilla japonica*)		F, M			+	
Cyprin (*Aphanius fasciatus*)		E		+		
Striped panchax (*Aplocheilus lineatus*)		F, E		+		
Blue panchax (*Aplocheilus panchax*)		F, E		+		
Alluaud's haplo (*Astratoreochromis alluaudi*)		F		+		
Chameleon cichlid (*Australoheros facetus*)		F		+		
Blackfin pearlfish (*Austrolebias nigripinnis*)		F		+		
Chubbyhead barb (*Barbus anoplus*)		F		+		
Silver (Java) barb (*Barbonymus gonionotus*)		F			+	
Slim betta (*Betta bellica*)		F		+		
Crescent betta (*Betta imbellis*)		F		+		
Penang betta (*Betta pugnax*)		F		+		
Siamese fighting fish (*Betta splendens*)		F	+	+		
Indian carp (*Catla catla*)		F			+	+
Lemonpeel angelfish (*Centopyge flavissimus*)		M		+		
Northern snakehead (*Channa argus argus*)	+	F			+	
Blotched snakehead (*Channa maculata*)		F			+	
Clown knifefish (*Chitala chitala*)		F	+	+		
Clown featherback (*Chitala ornata*)		F	+	+		
Peacock cichlid (*Cichla ocellaris*)	+	F		+		+
Speckled pavon (*Cichla temensis*)		F				+
Black acara (*Cichlasoma bimaculatum*)		F		+		+
Guayas cichlid (*Cichlasoma festae*)		F		+		
Mrigal carp (*Cirrhinus cirrhosis*)		F			+	
Mud carp (*Cirrhinus molitorella*)		F			+	
Hong Kong catfish (*Clarias fuscus*)		F			+	
North African catfish (*Clarias gariepinus*)		F			+	
Bighead catfish (*Clarias macrocephalus*)		F, E			+	
Splash tetra (*Copella arnoldi*)		F		+		
Bronze corydoras (*Corydoras aeneus*)		F		+		
Pearl danio (*Danio albolineatus*)		F		+		
Blackspot barb (*Dawkinsia filimentosa*)		F		+		
Malabar danio (*Devario malabaricus*)		F		+		
Northern pike (*Esox lucius*)	+	F, E				+
Pearlspot (*Etroplus suratensis*)		F, E		+		
Dominican gambusia (*Gambusia dominicensis*)		F		+		
Eastern mosquitofish (*Gambusia holbrooki*)		F		+		
Pearl cichlid (*Geophagus brasiliensis*)		F		+		
Redstriped eartheater (*Geophagus surinamensis*)		F		+		

Black tetra (*Gymnocorymbus ternetzi*)		F		+		
Siamese alga-eater (*Gyrinocheilus aymonieri*)		F		+	+	
Kissing gourami (*Helostoma temminckii*)		F		+		
Banded jewelfish (*Hemichromis fasciatus*)		F		+		
Head-and-taillight tetra (*Hemigrammus ocellifera*)		F		+		
African bony tongue (*Heterotis niloticus*)		F		+	+	
Stinging catfish (*Heteropneustes fossilis*)		F, E		+	+	
Atipa (*Hoplosternum littorale*)		F			+	
Jewel tetra (*Hyphessobrycon eques*)		F		+		
Armored catfish (*Hypostomus watwata*)		F		+		
Bata (*Labeo bata*)		F			+	+
Orangefin labeo (*Labeo calbusa*)		F			+	
Rohu labeo (*Labeo rohita*)		F			+	
Blue mbuna (*Labeotropheus fuelleborni*)		F		+		
Barramundi (*Lates calcarifer*)		F, E, M			+	+
Nile perch (*Lates niloticus*)	+	F			+	+
Banded leporinus (*Leporinus fasciatus*)		F		+		
Cuban limia (*Limia vittata*)		F, E		+		
Leaping mullet (*Liza saliens*)		M				+
Blacktail snapper (*Lutjanus fulvus*)		M				+
Bluestripe snapper (*Lutjanus kasmira*)		M				+
Paradise fish (*Macropodus opercularis*)		F		+		
Cichlid (*Maylandia lombardoi*)		F		+		
Golden mbuna (*Melanochromis auratus*)		F		+		
Bluegray mbuna (*Melanochromis johannii*)		F		+		
Odontobutid goby (*Micropercops swinhonis*)		F		+		
Ornate ctenopoma (*Microctenopoma ansorgii*)		F		+		
Asian swamp eel (*Monopterus albus*)		F, E			+	
Redtail notho (*Nothobranchius guentheri*)		F		+		
Argentine silverside (*Odontesthes bonariensis*)		F			+	+
Cloister blenny (*Omobranchus elongatus*)		M		+		
Gossamer blenny (*Omobranchus ferox*)		E		+		
Pink salmon (*Oncorhychus gorbuscha*)		F, M				+
Three spotted tilapia (*Oreochromis andersonii*)		F			+	
Cichlid (*Oreochromis leucostictus*)		F			+	
Longfin tilapia (*Oreochromis machrochir*)		F			+	
Sabika tilapia (*Oreochromis spilurus*)		F			+	
Japanese rice fish (*Oryzias latipes*)		F		+		
Giant gourami (*Osphronemus goramy*)		F		+	+	
Red top cichlid (*Otopharynx lithobates*)		F		+		
Marble goby (*Oxyeleotris marmorata*)		F		+		
Golden panchax (*Pachypanchax playfairii*)		F		+		
Red seabream (*Pagrus major*)		M			+	
Striped catfish (*Pangasianodon hypophthalmus*)		F			+	
Pangas catfish (*Pangasius pangasius*)		F, E			+	
Neon tetra (*Paracheirodon innesi*)		F	+	+		
Indian glassy fish (*Parambassis ranga*)		F		+		
Cobit loach (*Paramisgurnus dabryanus*)		F		+		
Golden barb (*Pethia gelius*)		F		+		
Black ruby barb (*Pethia nigrofasciata*)		F		+		
Striped poison-fang (*Petroscirtes breviceps*)		M		+		
Dusky millions fish (*Phalloceros caudimaculatus*)		F		+		
Ayu sweetfish (*Plecoglossus a. altivelis*)		F, E, M			+	
Emperor angelfish (*Pomacanthus imperator*)		M		+		
Devil firefish (*Pterois miles*)		M		+		
Freshwater angelfish (*Pterophyllum scalare*)		F		+		
Spotted barb (*Puntius binotatus*)		F		+		
Checkered barb (*Puntius oligolepis*)		F		+		

Halfbanded pyrrhulina (*Pyrrhulina laeta*)		F		+		
Blackline rasbora (*Rasbora borapatensis*)		F		+		
Three-lined rasbora (*Rasbora trilineata*)		F		+		
Rosy bitterling (*Rhodeus o. ocellatus*)		F		+		
Roach (*Rutilus rutilus*)	+	F, E				+
Mango tilapia (*Sarotherodon galilaeus*)		F, E			+	
Blackchin tilapia (*Sarotherodon melanotheron*)		F, E			+	
African butter catfish (*Schilbe mystus*)		F		+		
Asian bonytongue (*Scleropages formosus*)		F		+		
Nembwe (*Serranchromis robustus jallae*)		F				+
Marbled spinefoot (*Siganus rivulatus*)		M			+	
Cyprin barb (*Systomus partipentazona*)		F		+		
Sumatra barb (*Systomus tetrazona*)		F		+		
White Cloud minnow (*Tanichthys albonubes*)		F		+		
Spotted tilapia (*Tilapia mariae*)	+	F, E			+	
Banded tilapia (*Tilapia sparrmanii*)		F			+	
Putitor mahseer (*Tor putitora*)		F			+	+
Thick lipped gourami (*Trichogaster labiosa*)		F		+		
Dwarf gourami (*Trichogaster (Colisa) lalius*)		F	+	+		
Moonlight gourami (*Trichogaster microlepis*)		F		+		
Pearl gourami (*Trichopodus leeri*)		F		+		
Snakeskin gourami (*Trichopodus pectoralis*)		F		+	+	
Croaking gourami (*Trichopsis vittata*)		F		+		
Lake Malawi cichlid (*Tropheops tropheops*)		F		+		
Yellowstriped goatfish (*Upeneus vittatus*)		M		+	+	
Vimba bream (*Vimba vimba*)		F, E				+
Yellow tang (*Zebrasoma flavescens*)		M		+		

Appendix 2. Animal species in the aquaculture and aquarium trade that have established in the wild in Mexico (after FishBase accessed May 2013, Flores Martínez et al. (2013), Contreras-Balderas (1999), García Martínez et al.(in press), CONABIO's list of risk species, and the site reports from this program). F = freshwater, E = estuarine or brackish, M = marine.[1] Native to parts of Mexico but translocate to elsewhere in the country. Used in 1 = ornamental trade, 2 = bred on farms in Mexico, 3 = aquaculture for food, 4 = sporting fish or bait for sport fishing

Species	**ISSG listed**	**Pathway to Mexico**	**Habitat**	**Use in Mexico:**			
				1	2	3	4
Fish							
Yellowfin goby (*Acanthogobius flavimanus*)	Yes	Ballast	F, E	+			
Patzcuaro chub (*Algansea lacustris*)[1]		Translocated	F	+			
Blueback shad (*Alosa aestivalis*)		Dispersal	M, F				+
American shad (*Alosa sapidissima*)		Dispersal	M, F				+
Convict cichlid (*Amatitlania (Archocentrus) nigrofasciata*)		Ornamental	F	+			
Rock bass (*Amblopilites rupestris*)		Released	F			+	+
Black bullhead catfish (*Ameiurus melas*)[1]		Translocated	F				+
Yellow bullhead catfish (*Ameiurus natalis*)[1]		Translocated	F			+	
Brown bullhead (*Ameiurus nebulosus*)[1]		Translocated	F				+
Midas cichlid (*Amphilophus citrinellus*)		Ornamental	F	+			
Fourspine stickleback (*Apeltes quadarcus*)		Dispersal	M, E, F	+			
Bighead carp (*Aristichthys (Hypophthalmichthys) nobilis*)	Yes	Released	F			+	+
Oscar (*Astronotus ocellatus*)		? in wild	F	+	+		
Mexican blind tetra (*Astyanax fasciatus*)[1]		Translocated	F	+			
Blind cave fish (*Astyanax mexicanus*)		Translocated	F	+			
Tinfoil barb (*Barbonymus schwanenfeldii*)		Ornamental	F	+			
Cherry barb (*Barbus (Carpoeta, Puntius) titteya*)		Ornamental	F	+	+		
Hong Kong pleco (*Beaufortia leveretti*)		Ornamental	F	+			
Pike killifish (*Belonesox belizanus*)[1]		Translocated	F	+			
Goldfish (*Carassius auratus auratus*)	Yes	Ornamental	F	+	+		
River carp sucker (*Carpoides carpio*)[1]		Translocated	F				+
Quillback (*Carpoides cyprinus*)		Released	F				+
Blue-spotted grouper (*Cephalopholis argus*)		Ornamental	M	+			+
Great snakehead (*Channa marulius*)	Yes	? in wild	F	+			
Indonesian snakehead (*Channa micropeltes*)		Ornamental	F	+			+
Striped snakehead (*Channa striata*)		? in wild	F	+		+	
Humpback grouper (*Chromileptes altivelis*)		Ornamental	M	+			+
Tiger guapote (*Cichlosoma (Parachromis) managuense*)		Ornamental	F	+			
Yellowjacket (*Cichlosoma (Parachromis) motaguense*)		Ornamental	F	+			
Convict cichlid (*Cichlosoma nigrofasciatum*)		Ornamental	F	+			
Salvin's cichlid (*Cichlosoma salvini*)[1]		Translocated	F	+			
Mayan cichlid (*Cichlosoma urophthalmus*)[1]		Translocated	F	+			
Walking catfish (*Clarias batrachus*)	Yes	Ornamental	F	+		+	
Cachama pacu (*Colossoma macropomum*)		Released	F			+	
Grass carp (*Ctenophyngodon idella*)	Yes	Released	F			+	
Red shiner (*Cyprinella lutrensis*)[1]	Yes	Translocated	F				+
Common carp (*Cyprinus carpio carpio*)	Yes	Released	F	+	+	+	
Carp (*Cyprinus rubofuscus*)		? in wild	F			+	
Zebra danio (*Danio (Brachydanio) rerio*)		Ornamental	F	+	+		
Gizzard shad (*Dorosoma cepedianum*)[1]		Translocated	F				+
Threadfin shad (*Dorosoma petenense*)[1]		Translocated	F				+
Plains killifish (*Fundulus zebrinus*)[1]		Translocated	F				+
Mosquito fish (*Gambusia affinis*)[1]		Translocated	F				
Tui chub (*Gila bicolor mohavensis*)		Released	F	+			
Arroya chub (*Gila orcutti*)		Released	F	+			
Royal gramma (*Gramma loreto*)[1]		Ornamental	M	+			
Jewel cichlid (*Hemichromis guttatus*)		Ornamental	F	+			
African jewelfish (*Hemichromis letourneuxi = bimaculatus*)		Ornamental	F	+			
Rio Grande cichlid (*Herichthys cyanoguttatus*)[1]		Translocated	F	+			
Two spot (*Heterandria (Xiphophorus) bimaculata*)[1]		Translocated	F	+	+		

Silver carp (*Hypophthalmichthys molitrix*)	Yes	Released	F			+	
Suckermouth catfish (*Hypostomus plecostomus*)		Ornamental	F	+	+		
Tessellated blenny (*Hypsoblennius invemar*)		Dispersal	M				
Channel catfish (*Ictalurus punctatus*)[1]		Translocated	F			+	
Redbreast sunfish (*Lepomis auritus*)		Released	F				+
Green sunfish (*Lepomis cyanellus*)[1]		Translocated	F	+			+
Warmouth (*Lepomis gulosus)*[1]		Translocated	F			+	+
Bluegill (*Lepomis macrochirus*)[1]		Translocated	F			+	+
Dollar sunfish (*Lepomis marginatus*)[1]		Translocated	F	+			+
Longear sunfish (*Lepomis megalotis*)[1]		Translocated	F	+			
Redear sunfish (*Lepomis microlophus*)		Released	F				+
Spotted sunfish (*Lepomis punctatus*)[1]		Translocated	F				+
Wuchang bream (*Megalobrama ambycephala*)		Released	F			+	
Rough silverside (*Membras martinica*)[1]		Dispersal	M				
Inland silverside (*Menidia beryllina*)		Dispersal	F, E				
Small mouth bass (*Micropterus dolomieu*)		Released	F				+
Large-mouth bass (*Micropterus salmoides*)[1]	Yes	Translocated	F			+	+
Pond (Dojo) loach (*Misgurnus anguillicaudatus*)	Yes	Ornamental	F	+		+	+
White bass (*Morone chrysops*)		Released	F				+
Stripped bass (*Morone saxitilis*)		Dispersal	M, F				+
Black carp (*Mylopharyngodon piceus*)		Released	F			+	
Orangespine unicorn (*Naso lituratus*)		Dispersal	M	+			
Round goby (*Neogobius melanostomas*)		Ornamental	F, E, M	+			
Golden shiner (*Notemygonus crysoleucas*)		Translocated	F				+
Rainbow trout (*Onchorhynchus mykiss*)[1]	Yes	Translocated	F			+	+
Blue tilapia (*Oreochromis aureus*)	Yes	Released	F			+	
Mozambique tilapia (*Oreochromis mossambicus*)	Yes	Released	F			+	
Nile tilapia (*Oreochromis niloticus*)		Released	F			+	
Wami tilapia (*Oreochromis urolepis hornorum*)		Released	F			+	
Tilapia (*Oreochromis urolepis urolepis*)		Released	F			+	
Rainbow smelt (*Osmerus mordax*)		Released	M, E, F				+
Royal pleco (*Panaque nigrolineatus*)		Ornamental	F	+			
Bay snook (*Petenia splendida*)[1]		Translocated	F			+	
Rosy barb (*Pethia (Barbus, Puntius) conchonius*)		Ornamental	F	+			
Pirapatinga (*Piaractus brachypomus*)		Released	F	+		+	
Rosy red minnow (*Pimephales promelas*)[1]		Ornamental	F	+			
Orbicular batfish (*Platax orbicularis*)		Ornamental	M, E	+			
Guppy (*Poecilia reticulata*)		Ornamental	F	+	+		
Common molly (*Poecilia sphenops*)		Ornamental	F	+			
Yucatan molly (*Poecilia velifera*)[1]		Translocated	F	+	+		
Porthole livebearer (*Poeciliopsis gracilis*)[1]		Translocated	F	+			
White crappie (*Pomoxis annularis*)		Released	F				+
Black crappie (*Pomoxis nigromaculatus*)		Released	F				+
Red lionfish (*Pterois volitans*)	Yes	Dispersal	M	+		+	
Snow pleco (*Pterygoplichthys anisitsi*)	Yes	Ornamental	F	+			
Vermiculated sailfin (*Pterygoplichthys disjunctivus*)	Yes	Ornamental	F	+			
Orinoco sailfin (*Pterygoplichthys multiradiatus*)	Yes	Ornamental	F	+			
Amazon sailfin catfish (*Pteygoplichthys pardalis*)	Yes	Ornamental	F	+			
Chinese barb (*Puntius semifasciolatus*)		Ornamental	F	+			
Red piranha (*Pygnocentrus natteri*)		Ornamental	F	+			
Motley catfish (*Pylodictis olivaris*)[1]		Released	F	+			+
Whiptail catfish (*Rineloricaria parva*)		Ornamental	F	+			
White bass (*Roccus chrysops*)		Released	F				+
Striped bass (*Roccus saxatilis*)		Released	M, F				+
Atlantic salmon (*Salmo salar*)		Released	F			+	+
Brown (Sea) trout (*Salmo trutta*)		Released	F			+	+
Brook trout (*Savelinus fontinalis*)		Released	F				+
Spotted scat (*Scatophagus argus*)		Ornamental	M, E	+			
Red drum (*Sciaenops ocellatus*)[1]		Dispersal	M			+	+
Gilt-head bream (*Sparus aurata*)		Escaped farm	M				+
Cichlid (*Thorichthys (Cichlosoma) elliot*i)[1]		Translocated	F	+			
Firemouth cichlid (*Thorichthys meeki*)		Ornamental	F	+			
Redbreast tilapia (*Tilapia rendalli*)		Released	F			+	
Redbelly tilapia (*Tilapia zillii*)	Yes	Released	F			+	

Threespot gourami (*Trichogaster (Trichopodus) trichopterus*)		Ornamental	F	+	+		
Chamaeleon goby (*Tridentiger trigonocephalus*)	Yes	Ballast	M, E	+			
Redhead cichlid (*Veija synspila*)[1]		Translocated	F	+			
Green swordtail (*Xiphophorus hellerii*)		Ornamental	F	+	+		
Variable platy (*Xiphophorus variatus*)[1]		Translocated	F	+			
Sailfin tang (*Zebrasoma veliferum*)		Ornamental	M	+			