Early detection and rapid response to invasive species at demonstration natural protected areas, Mexico

Domestic milking goats, Sierra San Francisco, El Vizcaíno Biosphere Reserve

Early detection and rapid response to invasive species at demonstration natural protected areas, Mexico

John Parkes

Kurahaupo Consulting, 2 Ashdale Lane, Strowan, Christchurch 8052, New Zealand (Email: john.parkes1080@gmail.com)

Peter Williams

Landcare Research, Private Bag, Nelson, New Zealand

Fase preparatoria del proyecto GEF 00081866

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

Primer informe de actividades presentado a

Programa de las Naciones para el Desarrollo México

Kurahaupo Consulting Contract Report: 2013/006

August 2013

Contents

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 Use of Biodiversity (CONABIO). The focus of the program is on prevention and rapid response to incursions, rather than management of long-standing problems caused by IAS already present 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.

As part of this program nine Protected Natural Areas (PNAs) were selected as sites for pilot field projects to be funded in the GEF program. Teams from the Instituto de Biología of Universidad Nacional Autónoma de México (UNAM) and ACMT-IMAC visited each site and produced a summary report (Flores Martínez et al. 2013) and nine site fact sheets. The aim of these reports was to:

- Analyse the use of IAS within each by collating information provided by institutions and agencies that promote the use of IAS and describe the key introduction pathways for IAS used in productive activities
- Analyse the capacities of CONANP and local stakeholders to implement management actions against the IAS.
- Explore the use of pilot projects that might be developed by managers of the PNAs.

To provide guidance for the implementation of this part of the program, *Kurahaupo Consulting* has been commissioned to report on how Early Detection Rapid Response (EDRR) principles could be developed for inclusion in site management plans. Therefore, this report largely focusses on species not yet recorded within the nine demonstration PNAs (Table 1) but that may be a risk to the biodiversity values should they arrive. The focus is largely on non-native species but includes some species native to Mexico but not to the particular PNA.

We visited two sites (El Vizcaíno and Sian Ka'an) in April 2013.

2 Objectives

- To discuss the elements and options to be considered in management plans to establish an EDRR concept or system in mainland Protected Natural Areas (PNAs) including protocols, regulations, activities, cost, timing and responsibilities for implementation during the FSP in order to control the spread of IAS in the nine selected PNAs.

3 Background information

3.1 The Protected Natural Areas

The main characters of the nine demonstration PNAs are noted in Table 1. They represent a wide range of climatic zones, human use and modification, size and degree of threat from new IAS.

Table 1. Summary information for nine Protected Natural Areas selected as demonstration sites for the GEF project. We have used data from Parks Watch (www.parkswatch.org) and the site reports in this program.[1] IAS are but one threat to the biodiversity and integrity of the PNAs.

Site	Area (ha)	Habitats	Resident human population	Main threats other than IAS[1]
Los Tuxtlas Biosphere Reserve	155, 122	Tropical moist forest. High altitude to coastal	27,646	Livestock, deforestation, hunting, fishing, water pollution, population growth
Cumbres de Monterrey	177,396	Coniferous forest and chaparral	2795	Agriculture, ranching, forestry, fishing
Sierra de Álamos	92,890	Lowland tropical deciduous forest evergreen pine-oak, thorny scrub	600	Livestock, agriculture
El Vizcaíno	2,546,790	Arid shrublands	44,446	Ranching cattle and goats, illegal hunting, agriculture, mining, aquaculture
Valle de Bravo	139,871	Water catchment,	176,565	Illegal logging, aquaculture
Cañón del Sumidero	21,789	Tropical deciduous forest, pine-oak forest, grasslands	2,163	Urban growth
Sian Ka'an	528,148	Tropical forest on limestone	345	Illegal bunting and fishing, cattle ranching, exploitation of forests
Tutuaca	444,488	Pine-oak forests	3,957	Fire, forestry, livestock
Marismas Nacionales	133,854	Mangroves, dune vegetation	0	Livestock, forestry, fishing

Each PNA is further sub-divided into management zones according to biological, physical and human use criteria. We do not have maps of these zones or current distribution of exotic species within the PNAs, but it is likely that fewest occur in the core areas and so EDRR might be more relevant to stop invasions from the buffers.

Buffer areas are sub-divided into four zones where preservation, sustainable use of natural resources, sustainable use of ecosystems, or recuperation are permited activities.

- Preservation sub-areas allow for scientific research and monitoring, environmental education and some limited productive activities by local communities that do not substantially alter the natural condition and where any negative impacts are regulated.

- Sustainable use of natural resources sub-areas allow for research and education as well as tourism with low impact. Exploitation of natural renewable resources that benefit local residents is allowed, as is harvesting of wildlife under a permit.
- Sustainable use of ecosystems sub-areas allow low-intensity agriculture, livestock, forestry and artisanal fishing uses that are sustainable and compatible with the conservation goals of the PNA.
- Recuperation areas are sub-areas where past impacts are being remediated.

3.2 Current management capacity at national and site level

Many government agencies are mandated to manage IAS in Mexico; some by sector, some by biosecurity pathway, some as regulators, and some as land managers. EDRR systems and who conducts them will differ in detail between these agencies and at different scales.

Within PNAs, CONANP is the land manager and has primary responsibilities to manage IAS. CONANP has limited capacity to actively manage any of the exotic species already present and affecting biodiversity values in the parks they manage. They have few staff with expertise in IAS planning in their central office, and between 6 and 27 staff in total at each PNA with no specialist staff in IAS management. PROFEPA has the legal capacity to regulate human uses of the parks, while SENASICA-SAGARPA may promote sustainable uses of exotic species in buffer zones in parks with consequent adverse impacts in core zones of the park. There may therefore be conflicts between these roles of government agencies. CONABIO is an information broker across government agencies (particularly the environmental agencies) and may commission or promote research. CONABIO has an interest in IAS management in PNAs and across Mexico as it is mandated to implement the National Biodiversity Information System. It does not manage land. SAGARPA agencies have an interest in IAS within PNAs in two aspects. They may promote the sustainable use of exotic species (some of which mat be IAS) to provide subsistence livelihoods for residents, and they have an interest when diseases or IAS affect these productive systems.

The national parks and biosphere reserves of Mexico are managed by CONANP. Current capacity within CONANP to actively manage IAS in the nine sites is largely absent (Table 2). It also appears to be difficult for PROFEPA to regulate human activities within the sites or to halt incursions of people or IAS into the pristine parts of the sites due to a lack of staff (e.g. one for the whole of the Vizcaino Bioshpere Reserve (www.patrkswatch.org/patrkprofile.php?1=enf&country=mex&park=vibr&page=thr)

To put this potential capacity into some context we can look at what other countries or National Parks systems allocate to managing IAS in parks and reserves . New Zealand is a country with very substantial IAS problems and this is reflected in substantial expenditure of about US$200 million per year in their management. The equivalent of CONANP, the New Zealand Department of Conservation (DOC), manages 8,500 km^2 or about 30% of the country with a staff of 518 general rangers covering both biodiversity and biosecurity management plus 16 planning staff. The IAS management is supported by 31 technical and science staff. It is not possible to separate the operational roles into just weed and pest management or just native species management but several hundred FTEs is estimated (Ben

Reddiex, DOC, pers. comm.). The department also outsources much of its delivery to private contractors and other regional governments, disease management agencies and private landowners which spend about as much again on IAS control. The state of Victoria in Australia has an equivalent agency, Parks Victoria, that manages the state's national parks. These cover 39,000 km^2 or about 18% of the state and are managed with a staff of 1100 FTEs of whom 88 manage weeds and pests (Ben Fahey, Parks Victoria, pers. comm.). The USA National parks Service manages 340,000 km^2 or 3.5% of the country with a total staff in its 'resource stewardship' function (which includes IAS management) of 3400 FTEs. It is difficult to determine the proportion of staff working on IAS in the USA.

These comparisons between countries need to be made with caution because the whole park and/or IAS management systems differ between jurisdictions and staff job descriptions or budgets are inconsistent.

Table 2. Current management capacity at nine PNAs

PNA	**No. staff in local CONANP**	**No. staff with specialist IAS management expertise**
Los Tuxtlas	12	
Cumbres de Monterrey	?	?
Sierra de Álamos	14	2 with some
El Vizcaino	21	Limited
Valle de Bravo	9	Limited
Cañón del Sumidero	10	Limited but increasing
Sian Ka'an	27	
Tutuaca	?	?
Marismas Nacionales	6	
Totals at demonstration PNAs	?	?
Totals at all PNAs	?	?
National Office	?	1

The Third Report by Flores Martínez et al. (2013) recorded projects aimed at IAS at the nine PNAs. Several sites have surveyed IAS issues, some have small control programs against weeds such as *Arundo donax* and *Ligustrum lucidum* (Cumbres de Monterrey), *Casuarina equisetifolia* (Sian Ka'an) and *Cupressus lindleyi* (Cañon de Sumidero), while three fund sterilization and control of cats and/or dogs.

There are university studies on IAS conducted at the sites (see the site reports and Flores Martínez et al. 2013). Most appear to be either surveys of the exotic species present or social studies to raise awareness about IAS among the local populations. Long-established areas such as Los Tuxtlas have several active university programs, which may explain the longer list of exotic species recorded at this site. One study we have seen measured the impact of feral goats on vegetation in Vizcaíno (Angulo Valdez et al. (2011).

3.3 Exotic non-native and out of place native species already present in the PNAs

It is important to know what exotic non-native and ‘out-of-place’ native species are already present within the PNAs so that new incursions can be identified as ‘new’ and enter an EDRR process. Even if present in the PNA, it may also be useful to know what their distribution is across the management zones if they are absent from core or pristine areas and managers aim to keep them out. Such lists have several purposes in relation to EDRR, i.e. to assist managers to predict risks and design surveillance systems to meet them. They allow managers to:

- Use the lists to predict what sort of IAS are most likely to invade the PNA. For example, trees seem to present most risk at Cañon del Sumidero but not at Vizcaíno.
- Formulate local black or white-lists so regulatory agencies can restrict the importation of new species for use in the zones allowing sustainable uses when they are not already present.
- Compare with national black-lists.

The site reports note the presence of 260 exotic species in the nine demonstration sites (Appendix 1) and 135 Mexican species that are ‘out-of-place’ within the sites (Appendix 2). Forty-eight species (including 26 plants, 7 fish and 6 mammals) were listed as particular concern. The exotic species are not present at all sites, with those sites with most human use (including those most frequented by researchers) recording most exotic species (Table 3). However, all these totals (particularly for plants and invertebrates) are likely to be underestimates. Evidence for this claim is that the sites with most species listed are also sites where most research activity occurs and one site noted only exotic trees.

Table 3. Numbers of exotic species of various types recorded in nine PNAs in Mexico.

1 – Los Tuxtlas; 2 – Cumbres de Monterrey; 3 – Sierra de Álamos - Rio Cuchujaqui; 4 – El Vizcaíno; 5 – Valle de Bravo; 6 – Cañon del Sumidero; 7 – Sian Ka’an; 8 – Tutuaca; 9 – Marismas Nacionales.

Class of IAS	**Number of species by site (see Appendix 1)**									
Site	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**All**
Terrestrial plants	68	72	45	26	24	17	17	7	1	190
% Trees	25	3	29	8	21	100	57	0.0	0	25
% Herbs, shrubs	46	53	38	50	17	0	29	57	100	43
% Grasses, sedges	29	44	33	42	63	0	24	43	0	33
Aquatic plants	10	5	6	5	2	1	3	1	1	19
% Freshwater	100	100	100	40	100	100	100	100	100	84.2
Marine	0	0	0	60	0	0	0	0	0	15.8
Invertebrates	1	1	0	0	0	0	4	0	2	8
Fish	8	3	3	0	4	4	4	1	1	16
Amphibians	1	1	0	1	1	1	0	0	0	2
Reptiles	6	1	0	1	0	1	0	0	0	7
Birds	4	0	2	3	3	0	0	0	0	6
Mammals	6	2	4	8	6	7	5	1	3	12
TOTAL	104	85	60	44	40	31	33	10	8	260

Mainland areas in the tropics tend to have fewer invasive species than mainland areas in temperate regions (Pysek & Richardson 2006). Nevertheless, we were struck by the relatively low numbers of non-native plants in the PNAs compared with, for example, the average number of such species (n = 119) in a sample of 25 areas managed by the US National Park Servive (Loope 1992) or the 370 non-native plants with 121 invasive and two transforming weeds in Kruger National Park in South Africa (Foxcroft et al. 2003). In the latter case most plants were introduced for horticultural purposes and their distribution is concentrated around human habitation (Foxcroft et al. 2008) and near roads (Foxcroft et al. 2010).

4 Early Detection Rapid Response in PNAs

Early Detection-Rapid response to a new species needs to follow a step-wise process (e.g. NISC 2003).

- First is to detect, report and confirm that a new species has been found.
- Second is to assess whether the new species is of sufficient threat to warrant any response, and if it does, who should respond.
- Third is to conduct a preliminary survey to confirm the new species is present and to delimit its extent. The purpose of this quick survey is to assess the scale of the response required. The question to be judged is whether a rapid response will deal with the problem at small cost, or whether the likely response is major, costly, and outcomes are not certain, thus requiring a full feasibility study of the options.
- Fourth is to mount the rapid response – assuming this achievable. If not, the step has to wait for the outcome of a formal feasibility study with its recommended action (eradication, containment, sustained control, do nothing) and appropriate funding and operational accountabilities.
- The final step in an EDRR process is to review whether the actions have succeeded, or if not to reconsider whether more of the same management is desirable or whether the project should evolve following a formal feasibility study.

Clearly, the timeframes for this process will always depend on the ability of people to work through this process, but it is also clear that the biological timeframe between arrival and establishment will depend on the life history of the IAS – some must dealt with very quickly while others will be slow to establish and spread so responses can be slower.

These steps are the same as for any national EDRR system where multiple agencies may have roles in all or parts of the process. However, a point of discussion for Mexican agencies is whether those managing the steps in a national EDRR system should also manage the same steps in a site-based system of EDRR. Budgets for EDRR are contingent on the arrival of new species – analagous to a fire-fighting service. If there are sufficient events a full-time service can be developed. However, if the work is periodic the staff planning and conducting EDRR (especially the RR component) will need to be employed on other tasks or contracted when required. For government agencies, such as CONANP, the other tasks might involve the other strategies required for IAS management.

An EDRR system within PNAs may have a spatial focus on the core areas of the PNAs (in which case new incursions may come from the buffer zones as well as elsewhere), or a whole-of-park focus (in which case species from adjacent areas or elsewhere are the risk).

This system may also set a baseline date for determining what is a “new” incursion. This may be ‘now’ or ‘the near future’ so only really new incursions will be considered. Alternatively, the baseline date many be ‘the recent past’ so that incursions that have not fully established may be considered for the rapid response component – albeit a delayed response. The latter option has some advantages so that IAS might be used in the GEF program to demonstrate the EDRR process (see section 5).

4.1 Surveillance

Surveillance for new species in the whole PNA or within core areas may be passive or active. Passive surveillance relies on people (residents, visitors, researchers) present in the PNA for other reasons to note and report any suspected new species. The advantage of a passive approach is that it provides a more continuous surveillance. The disadvantages of a passive approach are that it will report false positives for exotic species already present or for native species, although an ‘alert’ scheme to educate people regularly using the PNA would reduce these problems. Active surveillance by experts surveying the PNA for new species would be more reliable but has the disadvantage of expense and would only operate when the funds were available to conduct surveys and so may miss important incursions in time to respond quickly.

A sensible combination of the passive and active would be to educate the passive cohort to report any putative new species, and to focus the active cohort on areas of highest biodiversity value or areas of highest risk of invasion within the PNAs.

Alert lists:

An ‘alert’ list of 25 non-native species were recorded as having the potential to invade one or more of the demonstration sites (Table 4). This list is probably optimistically short, especially in areas with on-site or adjacent towns and cities. The number of weeds on 234 reserves in New Zealand was highly correlated with their proximity to towns (Timmins &Williams 1991), and we suspect the urban plantings in gardens in towns adjacent to the demonstration sites will similarly increase invasion risks.

We can also use the current list of exotic species (Appendix 1) to predict the type of species that might present risks. Apart from the trivial predictions marine species need saltwater, or that few aquatic species will present risks in arid sites, Table 3 suggests which type of plants (for example) appear to be best suited to each site, although this assumes such lists are complete.

Black and white lists:

CONABIO is also developing a national black list of species of concern. A black list names species (or classes of organisms) that are not allowed to be imported into Mexico. Not all species on a national list will present risks to a particular PNA, but local managers can use it to form an alert list of species that do present a possible risk to their park.

Most black lists, by implication, usually do not include IAS already present in the PNA unless importation of more of such species presents some transparent additional risk. All is permitted unless forbidden by the black list!

The advantages of local black lists for a PNA context include (a) focussing the attention of residents and agencies promoting use of species for productive purposes that some species are not a good idea even if they might be useful to some people in the PNA, (b) alerting PNA managers to species in adjacent areas (such as towns) that present risks to the PNA, and (c) ensuring dangerous incursions are promptly managed when detected in the PNA. 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, and this approach may be best for PNAs.

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 into the PNA. The disadvantages are that decision-makers have to know what species are already present in the PNA and people may be encouraged to illegally import new species rather than subject them to the risk analysis and possible rejection.

IAS within the sustained use buffer zones but not in the core areas of PNA:

We do not have sufficient detail on the status of all these species in the PNAs to distinguish between those most affecting biodiversity values. Information is needed on their distribution within the PNAs, within the different management zones (core areas, buffers, areas of restricted use), how they got there, their use, local perceptions of them, and on their impacts on biodiversity values.

It would be useful to separate the species listed in the Appendices into those that affect biodiversity values from those affecting mostly agricultural or productive values in the different management zones in the PNAs. Some species might be transformational if they spread across wide areas (e.g. lion fish, red palm mites, or buffel grass?), others might be less critical even if they spread widely (e.g. debateably the iceplant in Vizcaíno?), while others might have little impact (e.g. some of the emphemeral herbs?). Such data on distributions and potential impacts would allow the key species of concern to be identified and management priorities to be justified.

We cannot do these prioritisations here but we can set out an approach or set of strategic options for their management depending on such parameters, i.e. a combination of the problem posed by a species and its manageability can be used to sort the lists of exotic species in the appendices. Whether such manageability can be imposed is a moot point given current capacity.

Table 4. Species listed by Flores Martínez et al. (2013) as having the potential to invade one or more of the demonstration PNAs. Note: some are already present in some PNAs.

1 – Los Tuxtlas; 2 – Cumbres de Monterrey; 3 – Sierra de Álamos - Rio Cuchujaqui; 4 – El Vizcaíno; 5 – Valle de Bravo; 6 – Cañon del Sumidero; 7 – Sian Ka'an; 8 – Tutuaca; 9 – Marismas Nacionales.

Red = herbs and shrubs, green = grasses and sedges, blue = trees, yellow = animals, purple = marine species.

Y = noted as having greatest impact in the PNA by Flores Martínez et al. (2013); EW = listed in at least one weedlist as likely to spread but no necessarily become a major problem; ISSG = listed on the ISSG's 100 worst invasive species; GIDB = listed in the Global Invasives Database for Mexico.

Species	**IAS**	**Protected Natural Area**								
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Terrestrial plants										
Amaranthus palmeri (Palmer's pigweed)*	EW									
Brassica tournefortis (Sahara mustard)	EW									
Cenchrus (Pennisetum) ciliaris (Buffel grass)	EW									
Chenopodium album (Fathen)	EW									
Chenopodium murale (Nettle-leafed goosefoot)	EW									
Cryptostegia grandiflora (Rubber vine)	EW									
Cyperus esculentus (Nut grass)	EW									
Oeceoclades maculata (Monk orchid)	Y									
Ricinus comminis (Castor oil plant)	EW									
Invertebrates										
Crassostrea gigas (Pacific oyster)	Y									
Dosidicus gigas (Humbolt squid)										
Pandinus imperator (Emperor scorpion)										
Fish										
Species in Loricariidae (Armored catfish)										
Oreochromis mossambicus (Tilapia)										
Reptiles										
Hemidactylus turcicus (Turkish gecko)										
Trachemys scripta elegans (Red-eared slider)										
Birds										
Myiopsitta monachus (Monk parakeet)	ISSG									
Streptopelia decaocto (Eurasian collared dove)	ISSG									
Mammals										
Bos taurus (Cow)										
Canis familiaris (Dog)										
Felis catus (Cat)	ISSG									
Mus musculus (House mouse)	ISSG									
Odocoileus virgineanus (White-tailed deer)										
Rattus rattus (Black rat)	ISSG									

Who should be responsible for surveillance within PNAs?

Current surveillance within PNAs is largely passive and ad hoc. The ‘alert’ list of IAS most likely to invade the PNAs, i.e. based on the species identified in the site reports (and collated in Appendices 1 – 3) should be developed within the FSP as publicity pamphlets for distribution to people using the PNA.

A formal survey of at least one PNA to list species held in adjacent towns, found in buffer zones and in core zones is recommended within the FSP to check the completeness of the current lists and to explore the spatial risk profile across the zonations around and within a park. We estimate 0.5 of a Full Time Equivalent (FTE), i.e. 2 people for 3 months would be required to survey and report for more complex PNAs with several towns within or adjacent to the park.

Active surveillance is expensive but a program to periodically survey at least core zones of the demonstration PNAs should be planned past the current GEF program. We estimate it would take 0.25 of an FTE, i.e. a plant and an animal ecologist for 1 month, to survey core zone(s) in a PNA.

4.2 Validating and determining the status of incursion

Whoever detects potential new species will need to have a clear process to report their find to a single person/position within an appropriate agency. Ideally, the report should be accompanied by a location and a specimen or photograph.

The report and/or specimen needs to be identified by an expert who then reports back to the detector thanking them for their vigilance, and to the person/agency who makes a decision on how to proceed. The expert’s name and authority should be attached to the identification and its archive record.

This phase of EDRR aims to convince those who have to approve and/or fund the project not only that it is worth doing but that the various ways of doing it have been considered. The ‘ways of doing it’ need to consider (a) which strategies are appropriate or possible – in this case a rapid response to remove or at least contain the incursion, (b) what tactics (control tools and methods) are available and best suited to the aim, (c) what set of options are likely to be supported by key stakeholders, and (d) give a first estimate of the costs and time the funding will be required. This process is essentially the same as done for larger projects to explore whether eradication is possible or, if not, what sort of ongoing management can be deployed – a feasibility study but one constrained by the need for haste.

CONANP is mandated to manage the PNAs so should be the primary response agency. PNA managers (in CONANP) need a policy to manage a confirmed new incursion that:

- Determines whether the incursion is primarily a problem for productive systems (and transition the response to SINEXE (Exotic and Emerging Diseases National Information System) or NED (National Emergency Dispositive Against Regulated Pests in Mexico), or is primarily a problem for biodiversity, or both.

- If a biodiversity threat, CONANP needs to manages the incursion, usually by eradicating the population within the PNA and/or its pathway of introduction to limit the chance of further incursions.

- Decides that the organism cannot be managed and no action is feasible.

- Formally transitions the response (or some part of it) to another agency or group better equiped or mandated to manage the incursion. It is desirable that CONANP has formal agreements in place with other government agencies (e.g. PROFEPA to manage regulated pathways such as deliberate introduction of new species into production zones within the PNA), and community organizations so the process for these formal transitions are pre-established and accepted.

- CONANP should be responsible for any rapid response component of this process, but if this fails to remove the threat and the IAS establishes the next steps should be to commission a formal feasibility study to determine what strategic options are possible, who should do it, and at what cost and who should fund it, i.e. a larger-scale eradication, containment, sustained control, or do nothing.

- Local CONANP staff might not have the knowledge to identify what expertise is available in Mexico (or elsewhere) so all reports and preliminary data should be sent to an agency who knows who to ask. Either CONABIO or CONANP head office would be suitable to achieve this initial validation, but whoever is responsible would need prior agreements, especially around matters of urgency, with appropriate taxonomists in universities (e.g. for plants and animals), or other government agencies (e.g. via the SINEXE or NED diagnostic laboratories if the new species is a disease or pest of agriculture).

- The appropriate response in an EDRR process is determined by the ability to quickly remove the incursion. The decision-maker requires specific knowledge on the scale of the incursion and so must have the funds and mandate to commission a rapid survey to delimit the area of the incursion. Knowledge on whether such an incursion can be removed is more likely to lie across a range of specialists so accessing this advice is also critical. A delimitation survey should simply ask the question ‘is the incursion established and breeding or not, very localised, patchily distributed, or widespread? Fine details are not required and the survey should be completed in days rather than weeks. The effort required is case and species dependent but should not be large. We recommend the responsible agency sets a small budget limit to enforce a rapid survey.

- The output from this is a decision to proceed (or not) and if the former a plan of action (allocate the task, provide a budget, pass on the information gathered to date).

- We estimate that 1 FTE would be required as a permanent position.

4.3 Rapid response

At this stage a decision to attempt to remove the incursion has been made, a budget allocated and a team to conduct the operation formed. Clearly, the response should begin as soon after the IAS is detected as possible if the IAS has the ability to reproduce and spread quickly. However, even when the IAS is not capable of an irruptive increase and spread, the timeframe to remove it should be as short as possible if only because funding is difficult to sustain in projects that drift past deadlines. What sort of team is an issue that will be case dependent.

- Generally, reliance on local communities or university staff/students to manage incursions of new IAS in PNAs will not be sufficient to effectively protect the biodiversity and integrity of Mexico's PNAs.
- Capacity to conduct IAS control operations at the park level will need to be developed, not just for EDRR but to manage the on-going problems caused by IAS. Some of the skills required, aligning operational expertise with academic study, have been developed by Grupo Ecologia y Conservacion de Islas (GECI) and their structure and process might form a template for the government agencies' requirements.
- The effort required for the Rapid Response component will be case-specific, but a rule of thumb might be that if it is predicted to require more than 2 FTEs over about 12 months then RR is probably not the appropriate action and a full feasibility study would be required to decide how to proceed.
- Funding the Early Detection component of EDRR can be base-lined in budgets. However, funding the Rapid Response component is contingent on finding incursions and so requires an 'emergency' budget structure. This is easier to justify at larger scales because generally there is a pipeline of work, but contingency budgets at the local scale are often difficult to manage.

The rules and contraints to remove an incursion are similar to those for eradication of an established population – it is just they have to be considered in haste of the response is to be 'rapid'. Eradication is the permanent removal of the whole population of pests. Once achieved it stops any further damage that the pest was causing and may allow natural recovery or active restoration of past damage. However, to achieve eradication some conditions should be met (Parkes & Panetta 2009):

- The average annual long-term rate of removal in source populations must be greater than the annual intrinsic rate of increase.

- There is no immigration of individuals that can breed. Logically this can never be quite met as the pest arrived once and could do so again. Therefore, on-going border management and surveillance is needed with the location of the effort along the risk chain (from source populations, on vectors such as ships, to the site being protected). This is based on assessment of the risks and likelihood of reinvasion and the costs of remedying any breach.

- There must be no net adverse effects. Eradication may not be desirable if the adverse effects on non-target species of the control methods available are predicted to be unacceptable and unresolvable, or if the consequences of removal of the pest outweigh the benefits (Courchamp et al. 2003).

Clearly, one has to have the tools to kill or remove the animals and a strategy to apply them to ensure all the above ‘start rules’ are met, and all the constraints on their application (stakeholder support, legal sanctions, environmental and non-target issues, funding, etc.) need to be overcome or managed. If the rules cannot be met and/or any constraints not overcome, then eradication is not possible, and setting it as a goal can distract from the planning required for optimal sustained control.

Eradication strategies fall into two categories. Some achieve their goal with a single event that, if done well, may kill 100% of the target population, e.g. the eradication of rodents using aerial baiting. Others achieve their goal by applying a sequence of events that successively reduce the target population to zero. These two types of eradication have quite distinct management consequences.

For the first type, managers get only one chance at success. In these cases, meticulous planning, over-engineering, fail-safe and back-up systems are the rule because everything must go right on the day (or few days) of the operations (Cromarty et al. 2002). The rule is ‘do not start unless it is all in place’. However, generally such methods (e.g. aerial baiting for insular rodents) provide no information on the success or failure from the operation itself and, because the cost or ability to detect and locate survivors (so any can be killed cheaply) is often more than the cost to repeat the whole operation, adherence to the start rules is the key to success.

For the second type of eradication, the sequence of control events themselves can provide managers with on-going information on the location and changes in numbers of survivors, such as GPS locations of traps or animals shot, trap-catch rates or kill-rates (Parkes et al. 2010). In the case of plants, time may reveal their reproductive potential and response to herbicides. This allows managers to be flexible and adaptive as the project proceeds, so having everything just right on day one is not as critical. However, for these projects it is the ‘stop rules’ that are difficult (Ramsey et al. 2011): how do you know that no animals are left when no more are seen or killed; and so when should you stop, demobilise and declare success? In this type of project it helps to think about managing it in phases:

Initial reduction of the population

Good maps showing where the pests are and are not (a delimitation survey) are an important input for planning an eradication operation. If the population is not present over the whole area, a general rule is to deal with outlying sub-populations first; at least if these are capable of sustaining themselves without input from the core populations, or if not to target the breeding core. This ‘rule’ has evolved from weed management where outliers may be self-sustaining. It is less rigid for animals where outlying groups may not be viable sub-populations and in fact rely on dispersal from the core population – in which case the core is the key target.

A second rule of thumb for this initial phase (when the target is an animal species) is to first use control methods that do not teach survivors to be wary. It is often a mistake to deploy all the control tools in the toolbox at once from the start. Sub-optimal control tools may kill a few animals but may also interfere with the effectiveness of the optimal methods.

The third rule of thumb is to attempt to do this initial phase as quickly as possible to avoid a drawn out process; if the initial phase is spread across many years, the population can replace a large part of their losses in every breeding season.

Therefore, some thought about the best sequence of control tools is required when several methods are available.

Removal of survivors

Most eradication attempts of this type reach the stage when only a small proportion of the original population is left. This often consists of old, wary individuals that have survived all thrown at them in phase 1, and/or are animals living in places where any control is difficult, e.g. the topography makes access hard, or the presence of people or livestock restricts the use of some control tools. Seed banks and persistant individuals sriviving earlier control are the analagous case for plants. Clearly good feasibility plans should predict how these survivors will be located and killed, and good operational plans should not leave such contingencies to chance.

What a Rapid Response component of an EDRR process must do is achieve eradication in one-hit or set short time-frames to reduce the population and remove survivors before the population establishes or spreads too widely.

4.4 Data management and reporting

In all cases CONANP head office if it develops the capacity (or CONABIO) should retain a metadata base of reported incursions, diagnoses and responses.

4.5 Validating outcomes

Eventually a stage is reached when no more animals or plants are found or killed and it might be that the rapid response has succeeded in eliminating the incursion. There are both informal and formal methods to judge whether this has been achieved.

Informal methods include waiting to see if the plants or animals become obvious after the control has stopped, or by conducting some arbitrary number of searches once the last known individual has been removed.

Formal methods take account of the problem that lack of evidence that survivors exist does not mean none are actually present. Formal methods use search and detection theory to give some probability that none found equals none left to be found, and how much more searching might be justified to raise this probability to a level commensurate with the residual risk of being wrong and falsely declearing success (e.g. see Ramsey et al. 2011; Samaniego-Herrera et al. 2013). These formal methods may be better suited to eradication projects on established population than to rapid response projects on incursions because they require either pre-determined detection probability parameters (the probability than if at least one individual is present it wil be detected by the search method or device), or there are enough data collected as a target population is reduced to collect this probability for the incursion population being removed. In the latter case the control method is often also the detection device.

5 Demonstration studies

One aim of the FSP is to explore the use of pilot studies with emphasis on those that prevent new incursions. For EDRR, the logical option is to wait until a new incursion is discovered in a PNA, perhaps one of those predicted as high risk in Table 3, and run the process described in section 4 as a pilot study. However, this is impractical because we cannot predict whether a suitable invasion will present itself over the immediate future in time to be used as a pilot project. The solution is to select some incursions already established in at least one PNA and test the EDRR process (or part of it) on them. The questions are which species at which sites and how many can be afforded?

Some rules for this selection are that the species should be localised or patchily distributed but with the ability to spread and so analagous to a recent incursion, listed on the 'alert' list (Table 4), a tractable problem so a pilot project has a good chance of success, a species present in several PNAs, and representative of a class of IAS.

Table 5 lists our suggestions for each site in a rough ranking so priorties can be applied as funds dictate. We suggest selecting at least one weed (*Casuarina equisitifolia* and/or *Arundo donax*) and one animal (the parrot at Guerrero Negro in El Vizcaíno) as pilot studies – or more if funds are available and local CONANP staff wish to participate.

The site report (Flores Martínez et al. 2013) notes the current work done at some of the sites by local NGOs or community groups. The FSP could invest funds in supporting action against some demonstration established IAS that are manageable (Table 5). We think this support should consist of technical support (from CONABIO or CONANP) to demonstrate how the eradication needs to be planned (as a template for eventual EDRR for new IAS) as well as funding to facilitate peoples' time and operating costs.

Table 5. Potential pilot species in each PNA.

PNA	Possible test IAS	Spatial distribution	On alert list from other PNAs	No. PNAs present	Tractability for management	Class of IAS
Los Tuxtlas	*Oeceoclades maculata*	In towns	Cañon del Sumidero	1	High	Terrestrial orchid
Cumbres de Monterrey	*Arundo donax*	Riparian	No	4	Moderate	Aquatic plant
Sierra de Álamos	*Tamarix ramosissima*	Patchy	No	1	Moderate	Tree
El Vizcaíno	*Myiopsitta*	In town	No	1	Moderate	Bird

	monarchus					
Valle de Bravo	*Micropterus salmoides*	?	No	3	Low	Fish
Cañon del Sumidero	*Felis catus*	Towns and ferals, widespread	Los Tuxtlas	6	Low	Mammal
Sian Ka'an	*Casuarina equisitifolia*	Coastal strip, patchy	No	3	Moderate	Tree
Tutuaca	*Oreochromis mossambicus*	Rivers	Sian Ka'an	3	Low	Fish
Marismas Nacionales	*Cissus sicyoides*	Mangroves	No	0	Unknown	Native Plant

If funding is limited, we suggest four species at four sites would test aspects of EDRR. As examples for the project and CONANP to consider we suggest:

Parrot population at Guerrero Negro:

The parrot at Guerrero Negro in Vizcaíno has been listed as *Forpus passerinus* and *Myiopsitta monachus* so validating which species is present would be needed[1]. Its establishment history current population size are known and it is apparently restricted to the town, although this would need to be confirmed by a delimitation survey. A feasibility plan would need to be developed to explore precedents for bird eradication (e.g. Copsey & Parkes 2013), what control methods are available and acceptable (e.g. trapping, shooting, netting, poisoning), and estimate how much it would cost to meet all the rules and constraints for eradication (Parkes & Panetta 2009). An attempt could then be made to remove the population and validate success by appropriate surveys. The wider project would need to encourage the local population that keep exotic birds not to keep risky species and to report (early detection) any escapes.

This example would require all the elements of a rapid response – initial assessment of the status of the population, feasibility and operational planning, an operation on the ground, and monitoring to judge success. It is large enough to require at least one person to manage the planning process (about 1 month) and perhaps 2 – 3 people to remove the birds over a short period. How long this would take is difficult to predict, but we would guess at least a year judging by other bird eradications of a similar size (e.g. pigeons (*Columba livia*) from three Galapagos islands; Phillips et al. 2012).

Sheoaks at Sian Ka'an:

The sheoaks (*Casuarina equisitifolia*) are native to Australia. At Sian Ka'an they were planted many decades ago to provide tall trees as shelter and shade around coastal holiday properties. They are now spreading. Elsewhere the species is known to adversely affect turtle nesting sites by binding the sand.

[1] It is the monk parrot according CONANP (Celerino Montes, pers. comm.).

The delayed response would require a delimitation survey and a survey of property owners to see which would allow access to remove the trees and seedlings. If access to all areas infested is not possible, then the positive response is one of containment rather than eradication and so either some ongoing budget (from CONANP) or short-term budget (via the GEF) to either conduct the surveys and perhaps demonstrate the best methods to halt dispersal.

Giant reed at one of several sites:

Giant reed (*Arundo donax*) is a tall perennial grass that grows in many-stemmed, cane-like clumps typically forming dense stands on disturbed sites, sand dunes, riparian areas and wetlands (Fig. 1). It is native to Spain but now widespread elsewhere in the world. It is recorded at five PNAs and occurs as a problem weed in many other places in Mexico (e.g. on the Rio Grande; Seawright et al. 2009). It is apparently spreading in some PNAs but restricted generally to wet, riparian sites. Thus an option for GEF pilot funding would be to determine the most efficient method to eradicate patches of the reed.

Figure 1. Giant reed on Laguna Muyil shore, Sian Ka'an showing rhizome structure (above).

Two demonstration sites have already conducted limited management of the giant reed so there are some data on precendents, and if these projects did not eradicate the target populations, on the minimun effort required for any pilot project. The weed is also the target of control in many places around the world so a pilot study could make a quick assessment of, for example, biocontrol (Seawright et al. 2009), and chemical and physical control (e.g. Mackenzie 2004), the latter at a cost of at least US$2500 per hectare.

Monk orchid at Los Tuxtlas:

The orchid (*Oeceoclades maculata*) is recorded as a potential IAS and is/was present as a horticultural plant in the Los Tuxtlas PNA. A project was conducted to convince residents to remove these plants, so a small GEF-funded project would be to follow up this advocacy to find out whether people have removed the incipient populations.

A fish at one site:

Removing established fish populations is very difficult but not impossible in enclosed waters (e.g. see Nico & Walsh 2011 for information on removal of tilapias). We have no data on the distribution of exotic fish within the PNAs but it might be possible to select an enclosed water body with recently-established fish populations and attempt to eradicate it – presumably using rotonone as a fish toxin.

We suspect the cost to achieve this and the scale of most problems (especially in rivers and in the sea) would drive management towards stopping incursions at their source rather than EDRR per se.

6 Recommendations

6.1 Recommendations for the FSP

A single government agency should have a mandated responsibility to overview the process to manage EDRR in PNAs. CONANP, as land manager, is one candidate for PNAs but they have no current capacity to do this and no mandate outside the parks. CONANP should conduct a gap analysis of its current capacity in IAS (see the lack of information in Table 2 of this report). CONABIO is in better position to provide wider oversight across both PNAs and other land tenures to manage EDRR for IAS threatening biodiversity outside PNAs.

We recommend that CONABIO provide oversight for the pilot projects (or more accurately the Rapid Response projects since the IAS are already present) in PNAs within the GEF project but suggest a decision then needs to be made about whether the future site-based

EDRR management is devolved to local CONANP managers, whether oversight is retained as part of the developing national EDRR for biodiversity protection, or subsumed into a national system for threats to biodiversity and productive sectors. The first option – developing local capacity within CONANP will be essential for at least the surveillance and operational response parts of an EDRR system for PNAs.

Some exotic species permitted within the buffer zones of PNAs are also IAS with respect to core zones. Site-specific blacklists would give guidance to the regulatory agency (PROFEPA) that some species not yet present should not be approved.

More complete surveys for IAS would be of value, especially in urban areas adjacent to the PNAs.

When eradication is the aim the project is best delivered by a dedicated team with the necessary skills and operating to a set of milestones and deadlines. Such a team may be from within the land or IAS managing agency as trained staff or (more commonly today) as contractors with the specialist skills. The latter can be more efficient than agency staff especially when performance-based or set price contracts are used (e.g. see the use of such contracts by The Nature Conservancy to drive efficient and successful feral pig eradication on Santa Cruz Island in California, USA; Morrison 2008).

6.2 Indicators of success for the FSP

Five pilot studies (the moderate to high tractability ones in Table 5) should be completed. The costs will be case-dependent and cannot be estimated until feasibility studies are completed, i.e. the scale of each project and who does it.

CONANP's capacity to manage an EDRR process should be developed with both national capabilities in planning and local capabilities to deliver the rapid responses that will arise. These capacities need to be but part of wider abilities to manage IAS and not just recent and new incursions.

Local communities and NGOs at each PNA should have a clear process to report suspected new IAS. Site-based blacklists for both the whole PNA and for core areas within the PNAs should be develped.

6.3 Recommendations for after the FSP

A small (2 FTEs) dedicated group should be formed at a national level within CONANP to plan key IAS projects more widely than just EDRR in PNAs. This group would prioritise projects, commission feasibility studies and liaise with local PNA staff to design and plan projects.

Mexico needs to develop capacity to manage IAS affecting biodiversity on the mainland. Planning by itself is no use unless it leads to action against priority IAS and/or priority sites. How such plans would be put into operation would depend on the type of project and the availability of local capacity (within agencies or within local communities) to deliver action on the ground. We note the current capacity to manage IAS on islands (by GECI) has developed some of the skills to act on plans. Some of GECI's skills are retained as full-time staff, some Mexicans are contracted for short periods during projects, while other people are contracted internationally when it is uneconomic to develop local infrastructure.

Increasing CONANP's capacity would free CONABIO to concentrate on its role as a coordinator between agencies and an information and research broker.

7 Acknowledgements

We thank Georgia Born and Brad Auer for comments on this review, and the staff of CONANP at Cancun and Guerrero Negro and local stakeholders for taking time to discuss their PNAs and issues in managing them.

8 References

Angulo Valdez CE, Orduño Cruz A, López Amador MCR (2011). Evaluación del impacto de caprinos en libre pastoreo sobre la vegetación en ranchos de l Sierra de San Francisco, Reserva de la Biosfera El Vizcaíno: bases para el diseño de estrategias de manejo zootécnico sustentable. Informe Técnico, Centro de Investigaciones Biologicas del Noroeste, S.C. Mexico, 35 p.

Copsey J, Parkes J (2013). Institutional capacity building for invasive bird management in the Pacific. Biodiversity Conservation Lesson Learned Technical Series 20. Conservation International, Apia, Samoa (www.conservation.org).

Courchamp F, Chapuis JL, Pascal M (2003). Mammal invaders on islands: im[act, control and control impact. *Biological Review 78*: 347–383.

Cromarty PL, Broome KG, Cox A, Empson RA, Hutchinson WM, McFadden I (2002). Eradication planning for invasive alien species on islands – the approach developed by the New Zealand Department of Conservation. In: Veitch CR, Clout MN (Eds.). Turning the tide: the eradication of invasive species. Occasional Paper of the IUCN Species Survival Commission No. 27: 85–91.

Flores Martinez J, García Ruiz, González Martinez C, Gutiérrez Granados G, González Salazae C, Mendieta Dorantes VJ (2013). Description of the status of current and potential EEI in 8 major PNAs, biodersity assessment of the relevance of these sites and existing and potential threats by IAS. Fase preparatoria del proyecto GEF 0081866.

Foxcroft LC, Henderson L, Nichols GR, Martin BW (2003). A revised list of alien plants for the Kruger National Park. *Koedoe 46*: 21–44.

Foxcroft LC, Richardson DM, Wilson JRU (2008). Ornamental plants as invasive aliens: problems and solutions in Kruger National Park, South Africa. *Environmental Management41*: 32–51.

Foxcroft LC, Jarosik V, Pysek P, Richardson DM, Rouget M (2010). Protected-area boundaries as filters of plant invasions. *Conservation Biology 35*: 400–405.

Koleff P, González AI, Born-Schmidt G (2010). National strategy for invasive species as a framework to develop weed management policies in Mexico. Weeds Across Borders.

Loope L (1992). An overview of problems with introduced plant species in National Parks and Bioshere Reserves in the United States.

MacKenzie A (2004). Giant reed. In: Harrington C, hayes A (Eds.). The weedworkers handbook. www.cal-ipc.org/file_library/19646.pdf.

Morrison SA (2008). Reducing risk and enhancing efficiency in non-native vertebrate removal efforts on islands: a 25 year multi-taxa retrospective from Santa Cruz Island, CA. In: Witmer GW, Pitt WC, Fagerstone KA (Eds.). Managing Vertebrate Invasive Species: proceedings of a symposium. USDA/APHIS/WS, Fort Collins, Colorado, USA. Pp. 398–409.

National Invasive Species Council (2003). General guidelines for the establishment and evaluation of invasive species early detection and rapid response systems. Version 1. NISC, Department of the Interior, Washington DC, USA.

Nico LG, Walsh SJ (2011).Non-indigenous freshwater fishes 0n tropical Pacific islands: a review of eradication efforts. In: Veitch CR, Clout MN, Towns DR (Eds.). Island invasives: eradication and management. Occasional Paper of the IUCN Spcies Survival Commsiion No. 42: 97–107.

Parkes JP, Panetta FD 2009. Eradication of invasive species: progress and emerging issues in the 21st century. In: Clout MN, Williams PA (Eds.). Invasive species management a handbook of principles and techniques. Oxford University Press, Oxford, 308 p.

Parkes JP, Ramsey DSL, Macdonald N, Walker K, McKnight S, Cohen BS, Morrison SA 2010. Rapid eradication of feral pigs (*Sus scrofa*) from Santa Cruz Island, California. *Biological Conservation 143*: 634–641.

Phillips RB, Cooke BD, Carrion V, Snell HL (2012). Eradication of rock pigeons, *Columba livia*, from the Galapagos Islands. *Biological Conservation 147*: 264–269.

Pysek P, Richardson DM 2006. The biogeography of naturalization in alien plants. *Journal of Biogeography 33*: 2040–2050.

Ramsey DSL, Parkes JP, Will D, Hanson CC, Campbell KJ (2011). Quantifying the success of feral cat eradication, Samn Nicolas Island, California. *New Zealand Journal of Ecology 35*: 163–173.

Samaniego-Herrera A, Anderson DP, Aguirre-Munoz A, Parkes JP (2013). Rapid assessment of rat eradication after aerial baiting. *Journal of Applied Ecology*

Seawright EK, Rister EM, Lacewell RD, McCorkle DA, Sturdivant AW, Goolsby JA, Yang C, Harris BL 2009. Economic implications of biological control of Arundo donax in the Texas Rio Grande Basin. Texas Water Resources Institute Report.

Timmins SM, Williams PA 1991. Weed numbers in New Zealand's forest and scrub reserves. *New Zealand Journal of Ecology 15*: 153–162.

Appendix 1 Species not native to Mexico present in nine Protected Natural Areas

1 – Los Tuxtlas; 2 – Cumbres de Monterrey; 3 – Sierra de Álamos - Rio Cuchujaqui; 4 – El Vizcaino; 5 – Valle de Bravo; 6 – Cañon del Sumidero; 7 – Sian Ka'an; 8 – Tutuaca; 9 – Marismas Nacionales.

Red = herbs and shrubs, green = grasses and sedges, blue = trees, yellow = animals, purple = marine species.

Y = noted as having greatest impact in the PNA by Flores Martínez et al. (2013); EW = listed in at least one weedlist as likely to spread but no necessarily become a major problem; ISSG = listed on the ISSG's 100 worst invasive species; GIDB = listed in the Global Invasives Database for Mexico.

Species	**Known IAS**	**Protected Natural Area**								
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Terrestrial plants										
Agrostis gigantea (Redtop grass)	EW									
Agrostis stolonifera (Creeping bent grass)	EW									
Albizia lebbeck (Yellow mimosa)										
Ambrosia artemisiifolia (Wormwood)										
Anagallis arvensis (Red pimpernel)										
Annona cherimola (Cherimoya)										
Artocarpus altilis (Breadfruit)										
Atriplex semibaccata (Australian saltbush)	EW									
Asphodelus fistulosus (Onionweed)	EW									
Avena fatua (Wild oat)	EW									
Bambusa arundinacea (Spiny bamboo)	Y									
Beta vulgaris (Beet)										
Bidens pilosa (Spanish needle)										
Bougainvillea glabra (Bougainvillea)										
Brachiaria brizantha (Signal grass)										
Brachiaria humidicola (Koronivia grass)										
Brassica juncea (Indian mustard)										
Brassica rapa (Rape)										
Bromus catharticus (Rescue grass)	EW									
Bromus tectorum (Downy brome)	EW									
Briza minor (Lesser quaking grass)	EW									
Cardamine hirsuta (Bittercress)	EW									
Cassia fistula (Golden shower tree)	EW									
Casuarina cunninghamiana (River oak)										
Casuarina equisetifolia (Sheoak)	YYY									
Cenchrus brownii (Slim bristle sandbur)	EW									

Cenchrus (Pennisetum) ciliaris (Buffel grass)	YY
Centaurea melitensis (Tocalote)	
Cerastium glomeratum (mouse-eared chickweed)	
Chenopodium murale (Nettle-leafed goosefoot)	EW
Chrysalidocarpus lutescens (Bamboo palm)	
Chrysanthemum coronarium (Chrysanthemum)	
Citrus aurantifolia (Lime)	
Citrus nobilis (Mandarin)	
Citrus sinensis (Orange)	
Citrus limonia (lemon x mandarin)	
Cocos nucifera (Coconut)	EW
Coffea arabica (Arabica coffee)	EW
Coffea borbon (Coffee)	
Coffea catura (Dwarf coffee)	
Coix lacryma-jobi (Job's tears)	
Colubrina asiatica (Asian snakewood)	GIDB
Coriandrum sativum (Coriander)	
Coronilla varia (Crown vetch)	EW
Coronopus didymus (Lesser swine cress)	EW
Cortaderia selloana (Pampas grass)	EW
Crepis (Youngia) japonica (False hawksbeard)	
*Crotalaria pumila (*Chipilan)	
Cucumis anguria (Bur cucumber)	
Cucumis melo (Musk melon)	
Cydonia oblonga (Quince)	
Cynodon dactylon (Bermuda grass)	Y
Cynodon plectostachyum (Giant star grass)	Y
Cyperus esculentus (Nut grass)	
Cyperus rotundus (Puple nut sedge)	GIDB
Dactyloctenium aegyptium (Crowfoot)	Y
Delonix regia (Framboyan)	EW
Desmodium procumbens (Trailing tricktrefoil)	
Dichanthium annulatum (Hindi grass)	
Digitaria bicornis (Crabgrass)	
Digitaria decumbens = eriantha (Pangola grass)	EW
Digitaria sanguinalis = ciliaris (Hairy crabgrass)	EW
Digitaria ternata (Crabgrass)	
Diplotaxis muralis (Annual wall-rocket)	
Echinochloa colona (Jungle rice)	EW
Echinochloa crus-galli (Barnyard grass)	EW
Eleusine indica (Indian goosegrass)	
Emilia sonchifolia (Lilac tasselflower)	
Eragrostis barrelieri (Mediterranean lovegrass)	EW
Eragrostis cilianensis (Stinkgrass)	
Eragrostis pilosa (Indian lovegrass)	EW
Erodium cicutarium (Common stork's bill)	
Eruca vesicaria (Rocket)	EW

Erucastrum gallicum (Common dogmustard)										
Eucalyptus camaldulensis (River red gum)	Y									
Eucalyptus globulus (Blue gum)	EW									
Euphorbia (Chamaesyce) hirta (Golondrina)	EW									
Euphorbia hyssopifolia (Sandmat)	EW									
Euphorbia lathyris (Caper spurge)										
Euphorbia prostrata (Prostrate sandmat)										
Festuca rubra (Red fescue)	EW									
Fiscus benjamina (Weeping fig)										
Foeniculum vulgare (Fennel)	EW									
Gliricidia sepium (Mata raton)	EW									
Gomphrena globosa (Globe amaranth)										
Guadua angustifolia (Thorny bamboo)										
Hackelochloa granularis (Pitscale grass)										
Hordeum glaucum (Barley grass)	EW									
Hordeum murinum leporinum (Wall barley)	EW									
Hibiscus rosa-sinensis (Rose mallow)	EW									
Hyparrhenia hirta (Thatching grass)	EW									
Imperata cylindrica (Cogon grass)	Y									
Lagenaria siceraria (Bottle gourd)										
Lantana camera (West Indian lantana)	Y									
Lantana hirsuta (Lantana)	EW									
Latuca sativa (Lettuce)										
Leonotis nepetifolia (Lions ear)	EW									
Ligustrum lucidum (Glossy privet)	Y									
Ligustrum sinense (Chinese privet)	EW									
Lobularia maritima (Sweet alyssum)										
Luffa aegyptiaca (Vietnamese gourd)										
Magnifera indica (Mango)										
Malus domestica (Apple)										
Manihot esculenta (Cassava)										
Marrubium vulgare (White horehound)	EW									
Medicago lupulina (Black medic)	EW									
Medicago polymorpha (Burclover)	EW									
Medicago sativa (Alfalfa)	EW									
Melia azedarach (White cedar)	GIDB									
Melilotis officinalis (Yellow sweet clover)	EW									
Melinis minutiflora (Molasses grass)	EW									
Melinis repens (Natal grass)	YY									
Mesembryanthemum crystallinum (Iceplant)	Y									
Miscanthus sinensis (Chinese silver grass)										
Mormodica charantia (Bitter melon)										
Musa X paradisiaca (Hybrid banana)										
Musa sapientum (Latudan banana)										
Nicandra physalodes (Apple of Peru)										
Odontonema cuspidatum (Firespike)										
Oxalis corniculata (Creeping wood sorrel)	GIDB									

Panicum antidotale (Blue panicgrass)										
Panicum repens (Torpedo grass)	EW									
Paspalum dilatatum (Dallisgrass)	EW									
Paspalum urvillei (Vasey's grass)	EW									
Pectis prostrata (Spreading cinchweed)	EW									
Pennisetum alopecuroides (Fountain grass)	EW									
Pennisetum clandestinum (Kikuyu grass)	EW									
Pennisetum purpureum (Elephant grass)										
Petroselinum crispum (Parsley)										
Phalaris minor (Lesser canary grass)										
Phoenix dactylifera (Date palm)	Y									
Pisum sativum (Green pea)										
Plantago lanceolata (Ribwort plantain)										
Plantago major (Greater plantain)										
Poa annua (Meadow grass)	EW									
Poa compressa (Canada bluegrass)	EW									
Poa pratensis (Kentucky bluegrass)	GIDB									
Polygonum aviculare (Common knotgrass)										
Polygonum persicaria (Spotted ladysthumb)										
Polypogon monspeliensis (Annual beard grass)	EW									
Polypogon viridis (Beard grass)	EW									
Prunus persica (Peach)										
Pueraria phaseoloides (Kudzu)	ISSG									
Punica granatum (Pomegranate)										
Raphanus sativus (Radish)										
Rhododendron indicum (Azalea)										
Rhus aromatica (Fragrant sumac)										
Ricinus communis (Castor oil plant)	YY									
Robinia pseudoacacia (Black locust)	EW									
Rumex acetocella (Sheep sorrel)	EW									
Rumex obtusifolius (Broad-leaf dock)	EW									
Saccharum officinarum (Sugarcane)										
Saponaria officinalis (Common soapwort)	EW									
Schinus terebinthifolius (Pepper tree)	Y									
Schismus barbatus (Common Mediterranean grass)	EW									
Senecio vulgaris (Common groundsel)	EW									
Senna bicapsularis (Rambling senna)	EW									
Senna multijuga (False sicklepod)										
Setaria adhaerens (Bur bristlegrass)										
Setaria verticillata (Bristly foxtail)	GIDB									
Setaria viridis (Green foxtail)										
Sisymbrium irio (London rocket)	EW									
Solanum nigrescens (Divine nightshade)										
Solanum seaforthianum (Brazilian nightshade)	EW									
Sonchus asper (Spiny sow thistle)	EW									
Sonchus oleraceus (Smooth sow-thistle)	EW									
Sonchus tenerrimus (Slender sow thistle)	EW									

Sorghum halepense (Johnson grass)	EW
Spathodea campanulata (African tulip tree)	Y
Tamarindus indica (Tamarind)	EW
Tamarix aphylla (Athel pine)	EW
Tamarix chinensis (Chinese tamarisk)	EW
Tamarix ramosissima (Salt cedar)	YY
Taraxicum officinale (Dandelion)	EW
Tectona grandis (Teak)	
Terminalia catappa (Bengal almond)	EW
Tibuchina urvilleana (Princess plant)	
Thunbergia fragrans (Black-eyed Susan)	EW
Tragus berteronianus (Spike bur grass)	
Trifolium repens (White clover)	GIDB
Triticum aestivum (Wheat)	
Urochloa (Panicum) maxima (Guinea grass)	EW
Vicia sativa (Common vetch)	EW
Vicia villosa (Hairy vetch)	EW
Vigna unguiculata (Cowpea)	
Vinca major (Blue periwinkle)	EW
Vulpia bromoides (Brome fescue)	
Vulpia myuros (Rat's tail fescue)	
Youngia japonica (False hawksbeard)	
Zinnia peruviana (Peruvian zinnia)	
Aquatic plants	
Arundo donax (Giant reed)	YYYY
Cladostephus spongiosus (Seaweed)	
Codium fragile (Green sea fingers)	EW
Cyperus alternifolius (Umbrella papyrus)	
Cyperus difformis (Variable flat sedge)	
Cyperus involucratus (African umbrella plant)	
Cyperus iria (Rice flat sedge)	
Cyperus odoratus (Flat sedge)	
Eichhornia azurea (Anchored water hyacinth)	EW
Eichhornia crassipes (Water hyacinth)	YYY
Ludwigia palustris (Water purslane)	
Mimulus guttatus (Common monkey flower)	
Pistia stratiotes (Water lettuce)	EW
Rorippa nasturtium-aquaticum (Watercress)	EW
Sagittaria sagittifolia (Arrowhead)	
Sargassum muticum (Japanese wire seaweed)	EW
Stenotaphrum secundatum (St Augustine grass)	
Symphiotrichum subulatum (Saltmarsh aster)	
Uruchloa mutica (Buffalo grass)	GIDB
Invertebrates	
Balanus Amphitrite (Acorn barnacle)	

Digitonthophagus gazella (Dung beetle)										
Litopenaeus vannamei (Whiteleg shrimp)										
Melanoides tuberculata (Red-rim melania)										
Mesocyclops aspericornis (Copepod)										
Mesocyclops thermocyclopoides (copepod)										
Procambrus clarkia (Freshwater crayfish)	GIDB									
Raoiella indica (Red palm mite)	Y									
Fish										
Carassius carassius (Crucian carp)	GIDB									
Cichlosoma managuensis (tiger guapote)										
Cyprinella lutrensis (Red shiner)										
Cyprinus carpio (Carp)	YYY									
Dorosoma petenense (Threadfin shad)										
Micropterus salmoides (Large mouthed bass)	YYYY									
Poecilia spenops (Common molly)										
Oncorhynchus mykiss (Rainbow trout)	Y									
Oreochromis (Tilapia) aureus (Blue tilapia)	Y									
Oreochromis mossambicus (Tilapia)	YYY									
Oreochromis niloticus (Nile tilapia)										
Species in Loricariidae (Armored catfish)	YYY									
Pterois volitans (Lion fish)	YY									
Tilapia rendalli (Redbreast tilapia)										
Tilapia zillii (redbelly tilapia)	GIDB									
Xiphophorus hellerii (Green swordtail)										
Amphibians										
Lithobates (Rana)catesbeianus (Bull frog)	Y									
Rhinella (Bufo) marina (Cane toad)	ISSG									
Reptiles										
Norops (Anolis) sagrei (Brown anole)	GIDB									
Hemidactylus frenatus (Asian house gecko)	YY									
Hemidactylus mabouia (House gecko)	GIDB									
Hemidactylus turcicus (Turkish gecko)										
Ramphotyphlops braminus (Brahminy blind snake)	GIDB									
Trachemys scripta elegans (red-eared slider)	Y									
Birds										
Columba livia (Feral pigeon)	Y									
Gallus gallus (Chicken)										
Molothrus bonariensis (Shiny cowbird)	GIDB									
Myiospitta monarchus (Monk parrot)	Y									
Passer domesticus (House sparrow)	Y									
Sturnus vulgaris (Starling)	ISSG									
Mammals										

Axis axis (Axis deer)										
Bos taurus (Cow)	YYY									
Canis familiaris (Dog)	YYY									
Capra hircus (Goat)	YY									
Equus asinus (Donkey)										
Equus caballus (Horse)	GIDB									
Felis catus (Cat)	YYYYYYY									
Mus musculus (House mouse)	YYYY									
Odocoileus virgineanus (White-tailed deer)										
Ovis aries (Sheep)	GIDB									
Rattus norvegicus (Norway rat)	GIDB									
Rattus rattus (Black rat)	YYYYY									

Appendix 2 Mexican species in 9 PNAs but outside their natural range

1 – Los Tuxtlas; 2 – Cumbres de Monterrey; 3 – Sierra de Álamos - Rio Cuchujaqui; 4 – El Vizcaino; 5 – Valle de Bravo; 6 – Cañon del Sumidero; 7 – Sian Ka'an; 8 – Tutuaca; 9 – Marismas Nacionales.

Red = herbs and shrubs, green = grasses and sedges, blue = trees, yellow = animals, purple = marine species

Y = noted as having greatest impact in the PNA by Flores Martínez et al. (2013); EW = listed in at least one weedlist as likely to spread but no necessarily become a major problem; ISSG = listed on the ISSG's 100 worst invasive species; GIDB = listed in the Global Invasives Database for Mexico

Species	**IAS**	**Protected Natural Area**								
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Terrestrial plants										
Acacia farnesiana										
Acalypha ostryifolia (Hophornbeam)										
Agonandra ovatifolia (Aceituna)										
Amaranthus palmeri (Careless weed)										
Ambrosia confertiflora (Weakleaf bur ragweed)										
Ambrosia psilostachya (Perennial ragweed)										
Annona muricata (Soursop)										
Anoda cristata = hastata (Violetta)										
Arachis hypogaea (Peanut)										
Argemone mexicana (Mexican poppy)										
Aristida ternipes (Spidergrass)										
Baccharus salicifolia (Mulefat)										
Bidens bigelovii (Beggars tick)										
Boerhavia coccinea (Scarlet spiderling)										
Boerhavia erecta (Erect spiderling)										
Bouteloua aristidoides (Needle gramma grass)										
Bouteloua barbata (Six-weeks gramma grass)										
Calyptocarpus vialis (Straggler daisy)										
Carica papaya (Papaya)										
Casimiroa sapota (White sapote)										
Cassytha filiformis (Love vine)	Y									
Castilla elastica (Panama rubber tree)										
Celtis laevigata (Southern hackberry)										
Celtis pallida (Desert hackberry)										
Cenchrus echinatus (Southern sandbur)										
Cenchrus incertus (Coastal sandbur)										
Chamaecrista absus (Sensitive pea)										

Chamaedorea humulis = elegans (Palmita)											
Chenopodium neomexicanum (N. Mexico goosefoot)											
Chloris virgata (Feather finger grass)											
Cissus sicyoides (Princess vine)	Y										
Conzya (Erigeron) canadensis (Horseweed)											
Crotalaria retusa (Wedge-leafed rattlepod)											
Cucurbita digitata (Fingerleaf gourd)											
Cucurbita foetidissima (Wild gourd)											
Cupressus lindleyi (White cedar)	Y										
Cuscuta americana (New Mexican goosefoot)											
Cynodon plectostachyus (Stargrass)											
Datura discolor (Desert thorn apple)											
Datura lanosa (Toloache)											
Datura stramonium (Jimson weed)											
Dasyochloa pulchella (Fluffgrass)											
Dieffenbachia seguine (Dumbcane)											
Diodia teres (Poorjoe)											
Dodonaea viscosa (Akeake)											
Eragrostis ciliaris (Gophertail lovegrass)											
Euphorbia eriantha (Beetle spurge)											
Euphorbia heterophylla (Fireplant)											
Eustachys (Chloris) petraea (Pinewood finger grass)											
*Fiscus yoponensis (*Fig)											
Fraxinus chiapensis (Tropical ash)											
Gaura parviflora (Velvetweed)											
Helianthus annuus (Sunflower)											
Helianthus niveus (Showy sunflower)											
Heliotropium torreyi (Slim-leafed heliotrope)											
Heterotheca subaxillaris (Camphorweed)											
Hydrocotyle verticillata (Whorled pennywort)											
Ipomoea cristulata (Morning glory)											
Jaltomata procumbens (Creeping false holly)											
Juglans major (Arizona walnut)											
Juniperus gamboana (Gambo juniper)											
Lantana urticoides (Texas lantana)											
Leucaena leucocephala (White acacia)	Y										
Lithospermum distichum (Panalillo)											
Litsea glaucescens (Mexican bay laurel)											
Lupinus arizonicus (Lupin)											
Machaeranthera tanacetifolia (Tahoka daisy)											
Mimosa aculeaticarpa (Catsclaw)											
Mirabilis longiflora (Maravillita)											
Mollugo verticillata (Carpetweed)											
Muhlenbergia fragilis (Delicate muhly)											
Muhlenbergia rigens (Deergrass)											
Muntingia calabura (Jamaican cherry)											
Nectandra ambigens (Laurel)											

Nicotiana glauca (Tobacco)											
Opuntia phaeacantha (Prickly pear)											
Orobanche cooperi (Desert broomrape)											
Orobanche multicaulis (Spiked broomrape)											
Panicum bulbosum (Bulb panicum)											
Paspalum vaginatum (Seashore paspalum)											
Persea americana (Avocado)											
Phaseolus vulgaris (Common bean)											
Physalis acutifolia (Tomatillo)											
Pinus patula (Mexican weeping pine)											
Pithecellobium dulce (Guamuchil)											
Polygonum lapathifolium (Pale smartweed)											
Populus fremontii (Alamo cottonwood)											
Portulaca suffrutescens (Shrubby purslane)											
Pseudognaphalium arizonicum (Arizona cudweed)											
Psidium guajava (Guava)											
Roystones regia (Cuban royal palm)											
Russelia equisitiformis (Coralillo)											
Sabal mexicana (Mexican palmetto)											
Sambucus mexicana (Mexican elderberry)											
Salix bonplandiana (Ahuejote)											
Senna pallida (Twin-flowered cassia)											
Setaria grisebachii (Bristlegrass)											
Sicyos deppei (Bur cucumber)	Y										
Solanum rostratum (Mexican thistle)											
Sporobolus indicus (Smut grass)											
Swietenia humilis (Pacific coast mahogany)											
Tecoma stans (Yellow bells)											
Tillandsia recurvata (Ballmoss bromeliad)	Y										
Trixis californica (American threefold)											
Vitis arizonica (Canyon grape)											
Vulpia octoflora (Sixweeks grass)											
Xanthosoma sagittifolium (Arrowleaf elephant ear)											
Aquatic plants											
Berula erecta (Water parsnip)											
Cyperus niger (Black flatsedge)											
Elodea canadensis (Pondweed)											
Equisitum laevigatum (Smooth horsetail)											
Eustachys petraea (Fingergrass)											
Phragmites australis (Reed)											
Typha dominguensis (Cumbungi)											
Typha latifolia (bulrush)	YY										
Invertebrates											
Macrodactylus mexicanus (Rose chafer beetle)											
Perkinsus marinus (Protozoan parasite of oysters)											

Rhynchophorus palmarum (Palm weevil)	Y									
Fish										
Astyanax fasciatus (Mexican tetra)										
Heterandria bimaculata (Twospot cichlid)										
Ictalurus punctatus (Channel catfish)										
Lepomis macrochirus (Bluegill)										
Membras martinica (Rough silverside)										
Petenia splendida (Bay snook)										
Thorichthys meeki (Firemouth cichlid)										
Xiphophorus maculatus (Southern platy)										
Xiphophorus variatus (Variegated platy)										
Amphibians										
Reptiles										
Drymarchon corais (Eastern indigo snake)										
Crocodylus moreleti (Mexican crocodile)										
Birds										
Bubulcus ibis (Cattle egret)	YY								+	+
Molothrus aeneus (Bronze cowbird)										
Quiscalus mexicanus (Mexican grackle)										+
Mammals										
Ammospermophilus leucurus (White-tail squirrel)										
Canis latrans (Coyote)										
Odocoileus virgineanus (White-tailed deer)										