Non-Native freshwater fish management in Biosphere Reserves

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Abstract

The consideration of non-native freshwater fish species in the management plans of 18 Biosphere Reserves is evaluated. Additionally, impacts caused by introduced freshwater fish species are described. Some measures to alleviate the ecological effects of fish species introductions are proposed, while paying attention to local development as well. The introduction of non-native species may have negative consequences for the ecosystems. The analysis of the management plans of the Reserves confirms that non-native freshwater fish species sometimes are not considered in the action plans of the area. Biosphere Reserve's management plans should consider the presence of alien species, with the aim to preserve biodiversity.

Keywords

Biodiversity management, introductions, translocations, invasive species, protected areas, ecological impacts

Bio-sketch

Andrea Pino-Del-Carpio is a PhD student developing their project about ecology river management in Biosphere Reserves. Rafael Miranda works in river management and biology of freshwater fishes. Jordi Puig develops his activity in the Landscape Planning and Fragmentation, and Environmental Impact Assessments.

Introduction, Hypotheses and Problems for Management

Biodiversity, the variety of life on Earth, is disappearing at an increasing and unprecedented rate (Rockström et al. 2009). This situation contradicts the 2002 objective to achieve a significant reduction of the current rate of biodiversity loss by 2010 (Convention on Biological Diversity 2002). One of the multiple initiatives adopted to promote biodiversity conservation has been the creation of areas protected by national governments. These areas may have different legal status, goals or land uses. Some of them can be considered worldwide natural areas of interest, such as World Natural Heritage sites, Ramsar sites, Special Protection Areas (SPA), Important Bird Areas (IBAS) and Biosphere Reserves.

Biosphere Reserves were created with the aim of reconciling the conservation of biodiversity, the social and economic development and the maintenance of cultural values in an area, which means to attain a sustainable use of resources. The concept of Biosphere Reserves was created in 1974 and it is defined in the Statutory Framework of the World network as "areas of terrestrial and coastal/ marine ecosystems, or a combination thereof, which are internationally recognized within the framework of UNESCO Programme on Man and the Biosphere (MaB)" (UNESCO 1996). To what extent Biosphere Reserves fulfil the aim of biodiversity conservation? In order to make a first inquiry in this issue, some Biosphere Reserve management plans have been reviewed, focusing on freshwater fish species.

The choice of this particular set of species responds to the hypothesis that some groups of animals or plants might be neglected in the management plans of Biosphere Reserves, whereas they should be properly dealt with because of their biological importance or their relevance as indicators of environmental quality. This might be the case of freshwater fishes, the most threatened group of vertebrates after amphibians; unless they are protected, 20% may become extinct in the next 25-50 years (Saunders et al. 2002).

According to recent researches, one of the major threats for native freshwater fishes, after habitat destruction, is the introduction of non-native species (Cambray 2003, Canonico et al. 2005). Are the occurrence and management of these non-native species properly considered in the Biosphere Reserves management plans?

The aim of this paper is to evaluate the consideration of non-native freshwater fish species in the management plans of 18 selected Biosphere Reserves. We evaluate whether these plans propose specific actions to deal with non-native freshwater fish species. The existing information on these species taken from the management plans has been complemented with inquiries across existing bibliography on the selected Biosphere Reserves under examination.

Complementarily, we describe some of the impacts caused by introduced freshwater fish species. Finally, we propose some measures to alleviate the ecological effects of fish species introductions, while paying attention to local development as well.

For the purposes of this assessment the definition of non native species does not imply or require that the species is harmful in any sense.

Methods

We have studied the management plans of 18 Biosphere Reserves, including three European Reserves – where freshwater fish knowledge is wide and more or less complete (Kottelat & Freyhof 2007)– six North, three Central and three South American Reserves; one from Australia and one from Asia, showing different levels of available data on freshwater fishes (Appendix 1). Biosphere reserves were selected according to non-native freshwater fish presence, published freshwater fish researches and management plans availability.

The reviews of the management plans and the published researches provided the raw data regarding the presence of non-native freshwater fish species. Some of the management plans were available online; others were requested to environmental authorities. At the same time, a bibliographic review of studies on native freshwater fishes within these Biosphere Reserves and the impact of the non-native species on them was carried out.

ISI web of knowledge (Thomson Scientific 2009) and Google Scholar databases were used to conduct the bibliographic review. Management plans and biblio-graphic data were confronted to obtain a complete list of non-native

Resumen

En este trabajo se evalúa la consideración de los peces dulceacuícolas alóctonos en los planes de gestión de 18 Reservas de Biosfera. Además, se describen los impactos causados por los peces dulceacuícolas introducidos. Se proponen algunas medidas para aliviar los efectos ecológicos de la introducción de peces, a la vez que se tiene en cuenta el desarrollo local. La introducción de especies exóticas puede tener consecuencias negativas en los ecosis-temas. El análisis de los planes de gestión de las Reservas confirma que los peces de agua dulce muchas veces no son considerados en los planes de acción del área. Lo planes de gestión de las Reservas de la Biosfera deberían considerar la presencia de especies exóticas, con el objetivo de salvaguardar la biodiversidad.

Palabras clave

Gestión de la biodiversidad, introducciones, translocaciones, especies invasoras, áreas protegidas, impactos ecológicos

species. Taxonomic review of scientific names was validated according to the W. N. Eschmeyer's Catalog of Fishes (Eschmeyer 2010) and the common names are used according to Nelson et al. (2004), Kottelat & Freyhof (2007), and Leunda et al. (2009). Lowe et al. (2000) list was used to inspect the percentage of alien species with a strongest invasive character at a global scale.

The management plans and bibliographic taxonomic data were confronted with the aim of detecting differences among them. Specific freshwater fish measures foreseen in management plans were analysed in the light of scientific information extracted from the bibliographical review.

Results

Due to the large amount of information managed, results and discussion will be centred about the most important findings. Complete results are detailed in Appendix 1.

Only eight of the 18 Biosphere Reserves had a specific management plan. Of the remaining 10 Reserves, six had management plans for the protected areas contained within them, and four did not even have any plan. The government of Chile informed us that the management plan for their particular Biosphere Reserve was in progress.

Eight of the 14 biosphere Reserves that had some kind of management plan (either for some of the parks contained within, or for the whole Biosphere Reserve) included indications on as how to manage freshwater fishes. Five of them had specific actions plans for non-native fish species, while six of them recognize the threat that non-native species represent. Nine of the 14 biosphere Reserves explicitly have rules that prohibit the introduction of non-native species. Specifically, Cinturón Andino Biosphere Reserve names two laws in the management plan. Only nine of the 14 reviewed management plans, recorded the presence of non-native freshwater fish species (Fig. 1a).

Taking into account the management plans and the bibliographic review, we found a total of 33 introduced and 18 translocated freshwater fish species for the 18 Biosphere Reserves. *Oncorhynchus mykiss*, *Cyprinus*

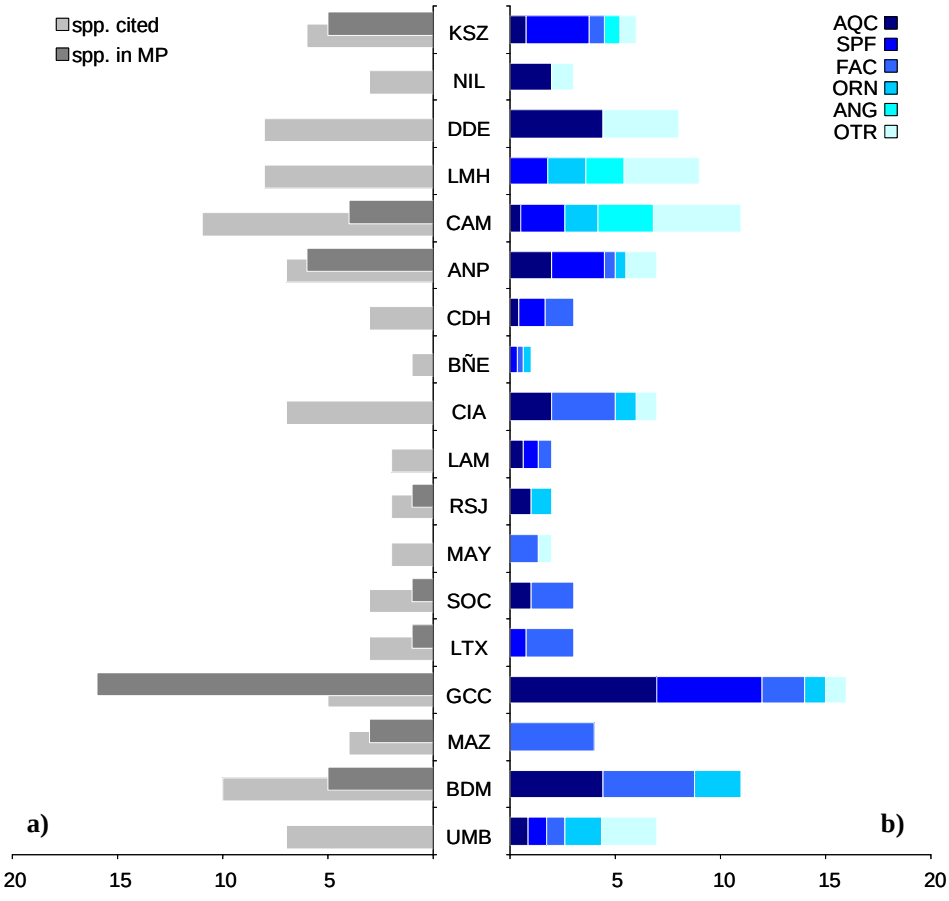

Fig. 1. a) number of cited species in the management plans (MP) and in the literature for the studied Biosphere Reserves; b) introduction routes (percentage). AQC: aquaculture, SPF: sport fishing, FAC: food and commerce, ORN: ornamental, ANG: angling, OTR: other reasons. Abbreviations of Biosphere Reserves names corresponds to Appendix 1.

carpio and *Oreochromis niloticus* were the non-native species with most occurrences in the studied Biosphere Reserves, followed by *Carassius auratus* and *Salmo trutta* present in five reserves (Fig. 2).

The main reason explaining the introduction of non-native freshwater fish species was aquaculture for food and fisheries' supply purposes (recreational and for commerce) (Fig. 1). Other reasons for the introduction are detailed in Appendix 1 and included purposes such as ornamental fishes, "improvement of wild stock", mosquito control, control of vegetation and accidental (e.g. ballast water of ships).

The impacts of the introduced species found in the literature are shown in Fig. 2. These impacts varied across the non-native fish species and were almost the same in every country where they were introduced, although the species affected by non-native fish may change in different countries. The most significant impact was predation (P) which affected native species like Galaxiids in Australia and Argentina, cyprinids, crayfish, amphibians and invertebrates, causing declines in their respective populations. Disturbance and alteration of ecosystem (HEA) was another important impact which was reflected in changes in water quality, depletion of vegetation, eutrophication, modification of substrate, and macrophytes, among others. Competition (C) was also represented, mainly for resources, such as food (TC) and habitat (HC); competition causes the displacement and reduction of abundance of native species.

Six of the 51 non-native freshwater fish species found for the 18 studied Biosphere Reserves are part of the 100 of world´s worst

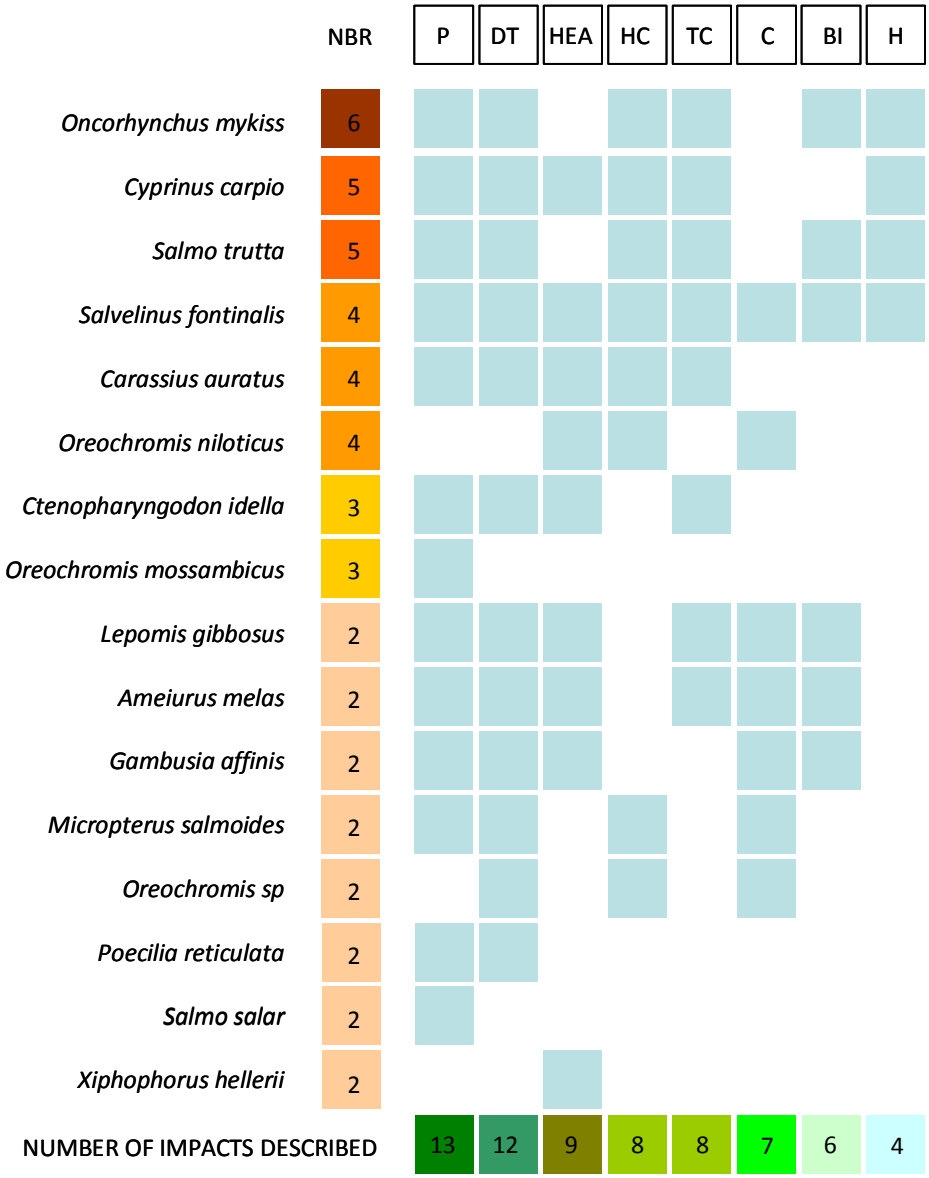

Fig. 2. Main non-native freshwater fish species, number of countries with Biosphere Reserves in which have become invasive (NBR), and impact mechanisms described within each Biosphere Reserve. P: predation, DT: disease transmission, HEA: habitat and ecosystem alteration, HC: habitat competition, TC: trophic competition (food), C: competition, BI: behavioural interference (aggressive behaviour), H: hybridization.

invasive species: *Salmo trutta*, *Cyprinus carpio*, *Micropterus salmoides*, *Oreochromis mossambicus*, *Oncorhynchus mykiss* and *Gambusia affinis*.

Discussion

Among vertebrates, introductions of freshwater fish species have been the most numerous. Even so, their impact on native fish fauna and their ecosystems are the least well documented (Crivelli 1995).

Introductions of non-native species worldwide were made mainly for aquaculture purposes, mostly for food, and also for recreational purposes, such as angling (Gozlan 2008). In fact, out of a total of 3141 new introductions recorded by FAO, 1386 resulted from this activity (Perez 2003). Likewise, aquaculture was the main reason of introduction of non-native species in the studied Biosphere Reserves.

However, we did find that the purpose of introduction of species may vary across different countries. An example of this is the common carp *Cyprinus carpio*, which was introduced in Spain as an ornamental fish, while in Mexico, Argentina, and the USA it was introduced as food resource, for commercial purposes, aquaculture, sport and as an ornamental fish. Another example is the goldfish *Carassius auratus*, which was introduced as an ornamental fish in Spain and the USA, and for fishery purposes in Rumania (Appendix 1).

Most of these introductions have been made regardless of the consequences for the ecosystems, as the effect on ecological interactions between species, hybridization with native species, loss of biodiversity, and introduction of new pathogens and diseases among others. In that sense Gozlan (2008) argued that on the global scale the majority of freshwater fish introductions are not identified as having an ecological impact while they do have great social benefits. This last statement can be controversial, as the effects of some freshwater species outside their native range and the impossibility to control the dispersal of introduced species (either voluntarily or accidentally) have been widely discussed.

At this point it is important to remember the objectives and criteria under which Biosphere Reserves were created. The most important aim of a Biosphere Reserve is to reconcile conservation of biodiversity and sustainable use of resources. To attain it is our obligation to ensure that Biosphere Reserves will keep their unique ecological systems while improving the livelihood of people living within them.

As the main cause of introduction of non-native freshwater fish species is aquaculture (food, sport fishing) it is necessary to consider other alternatives to the culture of these particular species. One of the most acceptable and easy achievable strategies would be to promote the culture of native species (de Silva et al. 2009). There is no reason to believe that some of the cultured alien species could not be replaced with indigenous species (de Silva et al. 2009). There are some examples, especially in Asia, where the culture of *Pangasianodon hypophthalmus* has proved to be a good substitute of non-native species without loss in production or socioeconomical benefits (de Silva et al. 2009). Another example can be found with the Mekong River Commission, established by an agreement between the governments of Cambodia, Lao, Thailand and Viet Nam. The Mekong River Commission established a programme with the goal to safeguard the indigenous fish species of the Mekong Basin. The aim of this programme was to develop aquaculture systems using indigenous Mekong fish species which may complement or replace exotic species (Petr & Swar 2002). In South Africa indigenous species have only recently appeared in the flyfishing spotlight due to dedication of conservation officials. Yellowfish

(*Labeobarbus* species) are proving to be popular and excellent angling species (Cambray 2003).

The replacement of non-native species with native species is an issue that must be considered, especially in countries with high freshwater fish biodiversity where it is easier to find suitable candidates (de Silva et al. 2009). The problem of attaining this strategy is that we must count on economical support to develop research projects on native fauna and its economical potential. This is a policy that should be outlined in the Biosphere Reserve management plans.

Although all Biosphere Reserves must have a management plan, as is recommended by UNESCO and the Seville Strategy, four of the studied Biosphere Reserves have not developed it. The absence of a management plan makes difficult to assess the presence of freshwater fish fauna, or any other resource that is present inside the Reserve; it also hampers the development of adequate conservation policies.

Of the 14 remaining Reserves, eight have developed actions related to freshwater fish management. These actions are sometimes unclear or ambiguous stating the need to strength research on both native and non-native fishes, develop monitoring programs or stocktaking. Only nine Biosphere Reserves recognize in their management plans the threat that non-native species represent for biodiversity, and six have developed specific plans for them, which involve control, eradication, and the preparation of complete databases of all introduced species. But the plans do not mention how they will carry out these actions. Some examples of actions implemented to manage non-native species are found in Australia where methods of control for salmonids have been applied on a relative small scale. Those methods include construction of barriers, followed by trout removal by poisoning and/or electrofishing for recovery of populations of galaxiids. Furthermore, trout was removed from a small lake by manual methods of gill nets, angling and baited long lines plus exclusion from access to spawning habitat (Jackson 2004). Elvira (1997) describes an example where selective fishing is used to control carps, goldfish *Carassius auratus* and their hybrids in the Laguna Zóñar, where there is a noticeable improvement in aquatic vegetation, macro-invertebrates and birds.

It is important to highlight that only nine reserves have recorded the presence of non-native freshwater fishes, although information from other sources on the occurrence of these species is available and should be considered in the management plans. Correct management actions can not be taken if there is incomplete scientific information. In that sense the presence of non-native fishes in Biosphere Reserves is a fact that must not be neglected. Although the consequences of their presence cannot be predicted with complete scientific certainty, we have to remember the potential risks that these species mean for native and freshwater ecosystems. Some well known examples of the risk of introductions are the Nile perch (*Lates niloticus)* whose introduction was followed by the extinction of 200 species of cichlids from Lake Victoria (Ross & Morales 2008, Strayer 2010), or the negative impact of introduced pike *Esox lucius* (Elvira 1995).

Besides, according to Copp (2005), translocations is the introduction of a species, from one part of a political entity (country) in which it is native to another part of the same country in which it is non-native. There are some assessments that report species as translocated in the studied Reserves: Pyrenean gudgeon *Gobio lozanoi* in Spain (Doadrio and Aldeger 2007, Leunda 2010); *Menidia jordani, Poeciliopsis gracilis* and *Xiphophorus helleri* (Contreras-MacBeath et al. 1998, Ibañez et al. 2008, Monks et al. 2005) in Mexico; *Galaxias brevipinnis* in Australia, (Waters et

al. 2002, Lintermans 2007), fish translocations in USA (Moyle 1976, Rahel 2000), like salmonids, centrarchids and percids for recreational or commercial purposes. Even so these species are not considered as non-native in the management plans.

Attention must be paid to translocations. In some cases they are made without any previous assessment about the potential impacts of these species, as it is assumed they not entail any threat because they are native to the region. As stated by Pusey (2006) and Burrows (2004) there is no reason to believe that the consequences derived from the introduction of non-native indigenous species would be any different to those arising from the introduction of fishes from other countries.

Conclusions

The introduction of non-native freshwater fish species may have negative consequences for the ecosystems. The analysis of the management plans of the Reserves confirms that non-native freshwater fish species are not considered in the action plans of the area. It is necessary to take effective measures for the control or eradication of these species. Future Biosphere Reserve's management plans should consider the presence of these alien species, with the aim to preserve conveniently the biodiversity.

Finally, it is necessary to remember that what makes Biosphere Reserves different from any other protected area is that they were made thinking about people, therefore it is essential to think about non-native species as an ecological issue but also keep in mind the uses and importance that these species have for the life of communities.

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Carps (*Cyprinus carpio*), tilapias (*Oreochromis niloticus*) and a bream (*Abramis brama*) captured by fishermen in the Barranca de Metztitlán Biosphere Reserve (Mexico)

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Appendix 1: Complementary information. This block summarises information on Biosphere Reserve studied, original sources and information therein presented and abbreviations/codes used through the paper.

Appendix 1.1: Tables.

Biosphere Reserve	Abbreviation Used	Country	Latitude	Longitude	Manage. plan	Actions	Action FWF	Actions N-NFWF
Cuenca Alta del Manzanares	CAM	Spain	40°30'-40° 49'N	03°33'-04° 00'W	[h]	RN, ER, C, R CT, ST, EC, M	CT, RN	
La Mancha Húmeda	LMH	Spain	38°52'-39° 10'N	02°45'-03° 47'W	[k]	M, CT,	CT	CT
Barranca de Metztitlán	BDM	Mexico	20°14'-20° 45'N	98°23'-98° 57'W	[f]	RN, M, R	RN	
Montes Azules	MAZ	Mexico	16°05'-16° 57'N	90°45'-91° 30'W	[p]	R		
Alto Golfo de California and Delta del Río Colorado	GCC	Mexico	31°00'-32° 10'N	113° 30'-115° 15'W	[q]	C, R, EC, CT, ER	R	R
Los Tuxlas	LTX	Mexico	18°05'-18° 45'N	94 35'-95 30'W	[g]	R, ST, C, CT, M, RN		
Selva el Ocote	SOC	Mexico	16°45'-17° 09'N	93°54' - 93° 21' W	[v]	M, R		
La Amistad	LAM	Costa Rica	08°44'-10° 02'N	82°43' - 83° 44'W	[e]	R, ST	R	R
Maya	MAY	Guatemala	17°49'-16° 48'N	89°09' - 90° 33'W	[i]	R		
Rio San Juan	RSJ	Nicaragua	11°29'-10° 42'N	84°21'- 83° 54'W	[o] [l] [m] [n]	R, RN, ST, M	R, M	M
Cinturón Andino	CIA	Colombia	00°51'-03° 59'N	75°16' - 77° 22'W	[r] [s] [t]	R, ER		
Bañados de Este	BÑE	Uruguay	32°00'-35° 00'S	53° - 55°W	[u]	C, EC, R, M		
Cabo de Hornos	CDH	Chile	54°09'-56° 18'S	70°92' - 67° 28'W	-			
Andino Nor Patagónica	ANP	Argentina	39°06'-43° 29'S	72°10' - 70° 56'W	[a] [b] [c] [d]	R, ER, EC, M, CT	M, CT, ER	CT, ER
Kosciuszco	KSZ	Australia	35°20'-37° 02'S	148°05'- 148° 50'E	[j]	CT, DB, M, R, C	DB, M, R	DB, M, R
Nilgiri	NIL	India	10°45'-12º15'N	76' - 77' 15' E	-			
Danube Delta	DDE	Rumania	44°20'-45° 27'N	28°10' - 29° 42'E	-			
University of Michigan Biological Station	UMB	USA	45°34'N	84°40'W	-			

Table 1: Actions proposed for studied Biosphere Reserves. Measures proposed for freshwater fishes (FWF) and for non-native freshwater fishes (N-NFWF). Letter Codes of Management plans (manage. plan) corresponds to bibliographic reference list. C: conservation of native species, CT: control, DB: database of exotics, EC: ecosystem conservation, ER: eradication, M: monitoring, R: research, RN: native reintroduction, ST: stocktaking.

Country	Species cited in Literature	Species cited in the corresponding Management Plan	Original Reasons for the species introduction	Source
Spain	*Oncorhynchus mykiss* (CAM, LMH)	*Salmo gairdneri* (CAM)	angling	[39] [31] [37]
	Carassius auratus (CAM, LMH)	*Carassius auratus* (CAM)	ornament	[39] [31] [37]
	Cyprinus carpio (CAM , LMH)	*Cyprinus carpio* (CAM)	ornament	[39] [31] [37]
	Salvelinus fontinalis (CAM)		angling	[39] [31] [37]
	Esox lucius (CAM, LMH)		angling, predator, sport fishing	[39] [31] [38] [11] [48] [37]
	Ameiurus melas (CAM)		"improvement of wild stock", sport fishing	[39] [81] [31] [51] [37]
	Gambusia holbrooki (CAM , LMH)		mosquito control	[39] [31] [20] [2] [1] [5] [120] [41] [100] [37]
	Lepomis gibbosus (CAM, LMH)		"improvement of wild stock", sport fishing, fishing bait, ornamental	[39] [84] [23] [100] [112] [37]
	Micropterus salmoides (CAM, LMH)		angling, sport fishing, predator	[39] [31] [100] [48] [30] [37]
	Alburnus alburnus (CAM)		angling, fishing bait, forage species	[39] [31] [116]
	Scardinius erythrophthalmus (LMH)		"improvement of wild stock"	[39] [31] [37]
	*Gobio lozanoi** (CAM)	*Gobio gobio gobio* (CAM)	aquaculture, fish bait, trout farming	[39] [32] [37]
Rumania	*Carassius gibelio*		aquaculture	[70]
	Hypophthalmichthys molitrix		aquaculture, Phyto- and zooplankton control	[106] [69]
	Lepomis gibbosus		spread by natural ways	[17]
	Pseudorasbora parva		accidentally with carp	[90] [20]
	Carassius auratus		fisheries	[106]
	Hypophthalmichthys nobilis		Aquaculture	[69]
	Ctenopharyngodon idella		improve fish production	[114]
	Polyodon spathula		escapes fish farming	[61]
Australia	*Salmo trutta*	*Salmo trutta*	recreational fisheries	[j] [77] [18]
	Salmo salar	*Salmo salar*	recreational fisheries, aquaculture	[j] [18]
	Oncorhynchus mykiss	*Oncorhynchus mykiss*	recreational fisheries, food	[j] [77] [18]
	Salvelinus fontinalis	*Salvelinus fontinalis*	recreational fisheries	[j] [77] [18] [125]
	*Galaxias brevipinnis**	*Galaxias brevipinnis*	water transfer	[125]
	Perca fluviatilis		angling	[118]
India	*Cyprinus carpio*		experimental culture	[9]

Table 2: Species recorded in the management plans and in the literature for the studied Biosphere Reserves (abbreviations of Biosphere Reserves names in brackets) and reasons of introduction. For references codes see Appendix 1.2. *Indicate translocated species. Cited literature corresponds only to reasons of introduction.

Country	Species cited in Literature	Species cited in the corresponding Management Plan	Original Reasons for the species introduction	Source
	Poecilia reticulata		mosquito control	[9]
	Oreochromis mossambicus		aquaculture	[9]
Mexico	*Cyprinus carpio* (BDM)	*Cyprinus carpio* (BDM, GCC)	food and commerce	[124] [103] [110] [22]
	Tilapia sp. (SOC)	*Tilapia sp.* (SOC)	aquaculture	[118]
	Abramis brama (BDM)		food and commerce	[58]
	Amatitlania nigrofasciata (BDM)		ornamental	[64] [22]
	Oreochromis niloticus	(BDM, MAZ, LTX, SOC)	food and commerce	[103] [123]
	Oreochromis niloticus	(BDM, MAZ, LTX)		
	Tilapia rendalli (BDM)	*Tilapia rendalli* (BDM)	food and commerce	[103] [62] [123]
	Oreochromis aureus (BDM, MAZ, LTX)	*Oreochromis aureus* (GCC)	food and commerce	[103] [62] [123]
	Ctenopharyngodon idella (MAZ)	*Ctenopharyngodon idella* (MAZ)	food	[22] [123]
	Oreochromis mossambicus	(MAZ, SOC)	food and commerce	[22] [62] [123]
	*Poecilia latipinna** (GCC)	*Poecilia latipinna* (GCC)	ornamental	[101]
	*Micropterus salmoides** (GCC, LTX)	*Micropterus salmoides* (GCC)	food and commerce, sport fishing	[22] [101]
	Tilapia zilli (GCC)	*Tilapia zilli* (GCC)	aquaculture	[123]
	Carassius auratus (BDM)		aquaculture	[123]
	*Menidia jordani** (BDM)		fisheries	[63]
	*Poeciliopsis gracilis** (BDM)		aquaculture	[22]
	*Xiphophorus helleri** (BDM)		ornamental	[22]
		*Pylodictis olivaris** (GCC)	aquaculture	[123] [79]
		*Ictalurus punctatus** (GCC, BDM)	aquaculture	[123]
		*Ictalurus furcatus** (GCC)	aquaculture	[123] [79]
		*Ameiurus natalis** (GCC)	aquaculture	[79]
		*Ameiurus melas** (GCC)	aquaculture	[123]
		*Chaenobryttus macrochirus** (GCC)	sport fishing	[98]
		*Lepomis gulosus** (GCC)	sport fishing	[98]
	*Chaenobryttuss cyanellus** (GCC)	*Ch. cyanellus** (GCC)	sport fishing	[98] [94]
		*Pomoxis nigromaculatus** (GCC)	sport fishing	[94]
		*Pomoxis annularis** (GCC)	aquaculture	[123]
	*Gambusia affinis** (GCC)	*Gambusia affinis** (GCC)	mosquito control	[101]
Colombia	*Oncorhynchus mykiss*		aquaculture	[26]
	Poecilia reticulata		mosquito control	[45]
	Xiphophorus hellerii		ornament	[118]
	Oreochromis mossambicus		fish farming	[43]
	Oreochromis niloticus		fish farming	[43]
	Tilapia rendalli		fish farming	[43]
	Salmo trutta		aquaculture	[118]
Nicaragua	*Oreochromis sp*	*Oreochromis sp.*	aquaculture	[76] [60]
	Hypostomus plecostomus		ornamental	[102]
Costa Rica	*Oreochromis niloticus*		food and commerce	[60]
	Oncorhynchus mykiss		aquaculture, sport	[118]
Guatemala	*Ctenopharyngodon idella*		control aquatic vegetation, food	[8]
	Oreochromis sp		control aquatic vegetation, food	[8]

Table 2 (cont.): Species recorded in the management plans and in the literature for the studied Biosphere Reserves (abbreviations of Biosphere Reserves names in brackets) and reasons of introduction. For references codes see Appendix 1.2. *Indicate translocated species. Cited literature corresponds only to reasons of introduction.

Country	Species Cited in Literature	Species cited in the corresponding Management Plan	Original Reasons for the species introduction	Source
Uruguay	*Oreochromis niloticus*		food and commerce, sport fishing, ornamental	[52]
Chile	*Oncorhynchus mykiss*		aquaculture, recreational fisheries, commerce, food	[52] [26] [107] [80]
	Salvelinus fontinalis		sport fish, food	[52] [80]
	Salmo trutta		sport fishing, food	[52] [80]
Argentina	*Oncorhynchus mykiss*	*Oncorhynchus mykiss*	aquaculture, recreational fisheries, export/trade	[52] [26] [87]
	Salmo trutta	*Salmo trutta*	sport fishing	[52] [87]
	Salvelinus fontinalis	*Salvelinus fontinalis*	aquaculture, sport fishing	[52] [87]
	Salmo salar	*Salmo salar*	aquaculture, export/trade, sport fishing	[52] [87]
	Oncorhynchus tchawytscha	*Oncorhynchus tchawytscha*	aquaculture, sport fishing	[52] [87]
	Oncorhynchus kisutch	*Oncorhynchus kisutch*	aquaculture, sport fish, export/trade, fill ecological niches	[52] [26] [87]
	Cyprinus carpio		food and ornamental	[52]
USA	*Carassius auratus*		aquarium release, pet release	[94] [82]
	Cyprinus carpio		aquaculture, food and sport purposes, comercial fishing	[94] [16] [82]
	Gymnocephalus cernuus		release of ship ballast water	[94] [16] [96]
	Misgurnus anguillicaudatus		ornamental	[82] [105] [109]
	Neogobius melanostomus		release of ship ballast water	[94] [96] [93] [68]
	Proterorhinus marmoratus		release of ship ballast water	[96] [93] [68]
	Salmo trutta		sport fishing	[94] [82]

Table 2 (cont.): Species recorded in the management plans and in the literature for the studied Biosphere Reserves (abbreviations of Biosphere Reserves names in brackets) and reasons of introduction. For references codes see Appendix 1.2. *Indicate translocated species. Cited literature corresponds only to reasons of introduction.

Family	Species	Ocurrences	Impacts	Source
Atherinidae	*Menidia jordani**	México (BDM)		
Centrarchidae	*Chanenobryttus cyanellus**	México (GCC)	P, C, BI	[35] [98] [79]
	*Ch. macrochirus**	México (GCC)	HEA, C, TC, BI, P	[59] [75] [98]
	Lepomis gibbosus	Spain (CAM, LMH), Rumania	P, HEA, TC, C, BI, DT	[4] [81] [84] [23] [3] [33] [99] [47] [5] [6] [13] [30] [115] [100] [112] [71] [54] [55] [53]
	*Lepomis gulosus**	México (GCC)	P, HEA	[89] [98]
	*Micropterus salmoides***	Spain (CAM, LMH), México (GCC, LTX)	P, HC, C, DT, H	[65] [4] [99] [53] [83] [46] [53] [14] [30] [92] [56] [13] [31] [38] [30] [71] [54] [55] [79]
	*Pomoxis annularis**	México (GCC)	P, C	[98]
	*P. nigromaculatus**	México (GCC)	P, C	[98] [7]
Cichlidae	*Oreochromis mossambicus*	Colombia, México (MAZ, SOC), India	P	[65]
	Oreochromis aureus	México (BDM, LTX, MAZ, GCC)		
	Oreochromis sp	Guatemala, Nicaragua	C, DT, HC	[76] [21] [60]
	Oreochromis niloticus	Colombia, Costa Rica, Uruguay, México (BDM, MAZ, LTX, SOC)	C, HC, HEA	[65] [60] [104]
	Tilapia sp	México (BDM, SOC)		
	Tilapia rendelli	México (BDM), Colombia		
	Tilapia zilli	México (GCC)		
	Amatitlania nigrofasciata	México (BDM)	HC	[22] [113]
Cobitidae	*Misgurnus anguillicaudatus*	USA	DT, TC, HC, P, HEA	[109]
Cyprinidae	*Abramis brama*	México (BDM)	HEA	[15] [111]
	Alburnus alburnus	Spain (CAM)	TC, P, H, DT, HEA, HC	[31] [116] [91] [71]
	Carassius auratus	Spain (CAM, LMH), México (BDM), Rumania, USA	P, HEA, TC, HC, DT	[65] [71] [50] [10] [38]
	Carassius gibelio	Rumania		[70]
	Ctenopharyngodon idella	Guatemala, México (MAZ), Rumania	P,HEA, TC, DT	[114] [108]
	Cyprinus carpio	Spain (CAM, LMH), México (BDM, GCC), Argentina, India, USA	HEA, H, P, DT, TC, HC	[65] [124] [122] [16] [31] [48] [50] [10] [5] [6] [71] [11] [38] [52]
	Scardinius erythrophthalmus	Spain (LMH)	H, HEA, P, C, DT	[31] [48] [71] [49]
	*Gobio lozanoi**	Spain	P, TC, HC, BI, DT	[71]
	Hypophthalmichthys molitrix	Rumania	HEA, TC, HC, BI, DT, Hy	[65] [69]
	Hypophthalmichthys nobilis	Rumania	HEA, TC, HC, BI, DT, Hy	[69]
	Pseudorasbora parva	Rumania	TC, HEA, P, DT	[119] [57] [90] [114]

Table 3: Systematic overview of species distribution among Reserves studied and the available literature about the impact mechanisms of introduced freshwater fishes. HEA: habitat and ecosystem alteration, P: predation, DT: disease transmission, BI: behavioural interference (aggressive behaviour), TC: trophic competition (food), C: competition, HC: habitat competition, H: hybridization. *translocated species **translocated species in Mexico. Biosphere Reserves are indicated in brackets. For abbreviations and codes see Table 1 (names of Reserves) and Appendix 1.2 (sources).

Family	Species	Ocurrences	Impacts	Source
Esocidae	*Esox lucius*	Spain (CAM, LMH)	P, DT, HC	[31] [40] [38] [4] [48] [34] [36] [29] [37] [71]
Galaxiidae	*Galaxias brevipinnis**	Australia	TC, HC, H	[73] [117] [66]
Gobiidae	*Neogobius melanostomus*	USA	TC, P, HC, C	[42] [67] [93] [68]
	Proterorhinus marmoratus	USA	C	[93]
Ictaluridae	*Ameiurus melas***	Spain (CAM), México (GCC)	HEA, P, TC, C, Bi, DT	[31] [51] [44] [72] [71] [101]
	*Ameiurus natalis**	México (GCC)	C	[79]
	*Ictalurus punctatus**	México (GCC, BDM)	C	[79]
	*Ictalurus furcatus**	México (GCC)		
	*Pylodictis olivaris**	México (GCC)	P	[79]
Loricariidae	*Hypostomus plecostomus*	Nicaragua		
Percidae	*Gymnocephalus cernuus*	USA	C, P	[16] [42]
	Perca fluviatilis	Australia	DT, P	[73]
Poeciliidae	*Gambusia holbrooki*	Spain (CAM, LMH)	P, C, BI, HEA, TC, HC, DT	[65] [86] [2] [97] [95] [30] [31] [71] [20] [1] [5] [6] [54] [78] [12] [120] [39] [38] [100] [37]
	Poecilia reticulata	Colombia, India	P, DT	[65]
	*Poecilia latipinna**	México (GCC)	HEA	[25]
	*Gambusia affinis**	México (GCC)	HEA, DT, BI, P, C	[65] [97] [101]
	*Xiphophorus hellerii***	Colombia, México (BDM)	HEA	[22]
	*Poeciliopsis gracilis**	México (BDM)	HEA	[22]
Polyodontidae	*Polyodon spathula*	Rumania		
Salmonidae	*Oncorhynchus mykiss*	Spain (CAM, LMH), Colombia, Costa Rica, Chile, Argentina, Australia	HC, P, H, DT, TC, BI, H	[65] [77] [107] [28] [85] [31] [30] [71] [88] [74] [29] [80] [73]
	Oncorhynchus kisutch	Argentina	P	[107] [88]
	Oncorhynchus tchawytscha	Argentina	P	[107] [88]
	Salmo trutta	Colombia, Chile, Argentina, Australia, USA	P, HC, H, TC, HEA, C,	[65] [27] [88] [74] [28] [82] [24] [107] [77] [80] [73]
	Salvelinus fontinalis	Spain (CAM), Chile, Argentina, Australia	HC, H, P, HEA, C, TC, BI, DT	[65] [77] [71] [31] [88] [74] [73]
	Salmo salar	Argentina, Australia	P	[107] [88] [73]

Table 3 (cont.): Systematic overview of species distribution among Reserves studied and the available literature about the impact mechanisms of introduced freshwater fishes. HEA: habitat and ecosystem alteration, P: predation, DT: disease transmission, BI: behavioural interference (aggressive behaviour), TC: trophic competition (food), C: competition, HC: habitat competition, H: hybridization. *translocated species **translocated species in Mexico. Biosphere Reserves are indicated in brackets. For abbreviations and codes see Table 1 (names of Reserves) and Appendix 1.2 (sources).

Appendix 1.2. Management plans, and references used in Tables 1-3.

Management Plans

[a] Administración de Parques Nacionales, Intendencia del Parque Nacional Lago Puelo. 2001. Parque Nacional Lago Puelo. Caracterización Ecológica, usos y estado de conservación. 42 pp.

[b] Administración de Parques Nacionales (APN). 1986. Plan de Manejo del Parque Nacional Nahuel Huapi. 99 pp.

[c] Administración de Parques Nacionales (APN). 1997. Plan Preliminar de Manejo Parque Nacional de Lanín. 112 pp.

[d] Administración de Parques Nacionales (APN). 1997. Plan Preliminar de Manejo del Parque Nacional Los Alerces. 85 pp.

[e] Centro Agronómico Tropical de Investigación y Enseñanza. 1987. Plan General de Manejo y Desarrollo del Parque Internacional La Amistad. 280 pp.

[f] Comisión Nacional de Áreas Naturales Protegidas CONANP. 2003. Programa de Manejo Reserva de la Biosfera Barranca de Metztitlán. 202 pp.

[g] Comisión Nacional de Áreas Naturales Protegidas CONANP, 2006. Programa de Conservación y Manejo Reserva de la Biosfera los Tuxtlas. 293 pp.

[h] Comunidad de Madrid, Dirección General de Educación y Prevención Ambiental. 1997. Plan rector de Uso y gestión del Parque Regional de la Cuenca Alta del Manzanares. 204 pp.

[i] Consejo Nacional de Áreas Protegidas-CONAP. 2001 Plan Maestro de la Reserva de la Biosfera Maya. 2001-2006. 98 pp.

[j] Department of Environment and Conservation NSW. 2006. Plan of Management Kosciuszko National Park. 326 pp.

[k] Dirección General de Medio Ambiente. 1995. Plan Rector de Uso y gestión del Parque Natural Lagunas de Ruidera. 46 pp.

[l] Dirección General de Áreas Protegidas del Ministerio del Ambiente y los Recursos Naturales (MARENA). 2003. Plan de Manejo del refugio de Vida Silvestre Los Guatuzos. 211 pp.

[m] Dirección General de Áreas Protegidas del Ministerio del Ambiente y los Recursos Naturales (MARENA). 2003. Plan de Manejo del Refugio de Vida Silvestre San Juan. 145 pp.

[n] Dirección General de Áreas Protegidas del Ministerio del Ambiente y los Recursos Naturales (MARENA). Plan de Manejo de la Reserva Natural Cerro Silva. 142 pp.

[o] FUNDAR-MARENA (2003). Plan de manejo del Monumento Histórico Fortaleza de la Inmaculada Concepción de María. Proyecto Gestión Ambiental Amigos de la Tierra/España – Cooperación Española Managua, Nicaragua. 181 pp.

[p] Instituto Nacional de Ecología SEMARNAP. 2000. Programa de manejo Reserva de la Biosfera Montes Azules. 256 pp.

[q] Instituto Nacional de Ecología SEMARNAP. 1995. Programa de manejo Reserva de la Biosfera Alto Golfo de California y Delta del Río Colorado. 76 pp.

[r] Ministerio de Ambiente, Vivienda y Desarrollo Territorial, Unidad Administrativa Especial del Sistema de Parques Nacionales Naturales. 2005. Plan de manejo 2005-2009 Parque Natual Cueva de los Guácharos. 196 pp.

[s] Ministerio de Ambiente, Vivienda y Desarrollo Territorial, Unidad Administrativa Especial del Sistema de Parques Nacionales Naturales. 2005. Plan Básico de Manejo 2005-2009 Programa Parque Nacional Natural Nevado del Huila. 393 pp.

[t] Ministerio de Ambiente, Vivienda y Desarrollo Territorial. 2004. Plan de Manejo básico del parque Nacional Natural Puracé. 211 pp.

[u] Programa de Conservación de la Biodiversidad y Desarrollo Sustentable en los Humedales del Este-PROBIDES. 1999. Plan Director Reserva de Biosfera Bañados del Este, Uruguay. 159 pp.

[v] Secretaria de Medio Ambiente y Recursos Naturales SEMARNAP. 2000. Programa de Manejo de la Biosfera Selva El Ocote. 144 pp.

References included in Tables 1-3.

[1] Alcaraz & Garcia-Berthou 2007, [2] Alcaraz et al. 2008, [3] Almeida et al. 2009, [4] Almodóvar & Elvira 1994, [5] Angeler et al. 2002a, [6] Angeler et al. 2002b, [7] Batzer et al. 2000, [8] Bestelmeyer & Alonso 2000, [9] Biju 2000, [10] Blanc 1997, [11] Blanco & Romo 2006, [12] Blanco et al. 2004, [13] Blanco-Garrido et al. 2009, [14] Bravo et al. 2001, [15] Breukelaar et al. 1994, [16] Brock & Crisman 1991, [17] Burlacu et al. 2009, [120] Cabral & Marques 1999, [18] Cadwallader 1996, [19] Caiola & de Sostoa 2002, [20] Caiola & de Sostoa, 2005, [21] Canonico et al. 2005, [22] Contreras-Macbeath et al. 1998, [23] Copp et al. 2004, [24] Copp et al. 2005, [25] Courtenay et al. 1974, [26] Crawford & Muir 2008, [27] Crivelli 1995, [28] Crowl et al. 1992, [29] de Sostoa & Lobon-Cervia 1989, [30] Doadrio 2001, [31] Doadrio 2007, [32] Doadrio & Madeira 2004, [33] Domínguez et al. 2002, [34] Dominguez & Pena 2000, [35] Dudley & Matter 2000, [36] Elvira 1990, [37] Elvira 1995, [38] Elvira 1997, [39] Elvira & Almodóvar 2001, [40] Elvira et al. 1996, [41] Fernández-Delgado & Rossomanno 1997, [42] French & Jude 2001, [43] Galvis & Mojica 2007, [44] Gante & Santos 2002, [45] Garcia et al. 2008, [46] Garcia-Berthou 2002, [47] Garcia-Bethou & Moreno-Amich 2000a, [48] Garcia-Berthou & Moreno-Amich 2000b, [49] Garcia-Berthou & Moreno-Amich 2000c, [50] Garcia-Berthou et al. 2007, [51] Garcia-de-lomas et al. 2009, [52] GISP 2005, [53] Godinho & Ferreira 1994, [54] Godinho & Ferreira 1998a, [55] Godinho & Ferreira 1998b, [56] Godinho & Ferreira 2006, [57] Gozlan et al. 2005, [58] Gutierrez-Cabrera et al. 2005, [59] Hambright et al. 1986, [60] Hernández et al. 2002, [61] Holčík 2006, [62] Ibañez 2004, [63] Ibañez et al. 2008, [64] Ishikawa & Tachihara 2010, [65] IUCN/ISSG 2010, [66] Jackson 2004, [67] Jude 1996, [68] Jude et al. 1992, [69] Kolar et al. 2005, [70] Kottelat & Freyhof 2007, [71] Leunda 2010, [72] Leunda et al. 2008, [125] Lintermans 2004, [73] Lintermans 2007, [74] Macchi et al. 2007, [75] Marchetti 1999, [76] McCrary et al. 2007, [77] McIntosh et al. 2010, [78] Mieiro et al. 2001, [79] Miller et al. 2005, [80] Moorman 2009, [81] Morillo et al. 1999, [82] Moyle 1976, [83] Nicola et al. 1996, [84] Oliva-Paterna et al. 2005, [85] Oscoz et al. 2005, [86] Oscoz et al. 2008, [87] Pascual et al. 2002, [88] Pascual et al. 2007, [89] Pearl et al. 2003, [90] Perdices & Doadrio 1992, [91] Perez-Bote et al. 2004, [92] Prenda & Mellado 1993, [93] Pronin et al. 1997, [94] Rahel 2000, [95] Reynolds 2009, [96] Ricciardi & MacIsaac 2000, [97] Rincón et al. 2002, [98] Rinne 2004, [99] Rodríguez-Jiménez 1989, [100] Rodríguez-Jiménez 2001, [101] Rush 2005, [102] Sánchez & Barnutti 2008, [103] Schüttler & Karez 2008, [104] Simoes et al. 2009, [105] Simon et al. 2006, [106] Sindilariu et al. 2006, [107] Soto et al. 2006, [108] Sutton 1977, [109] Tabor et al. 2001, [110] Tapia & Zambrano 2003, [111] Tátrai et al. 2009, [112] Tomecek et al. 2007, [113] Trujillo-Jimenez et al. 2009, [114] Van Zon 1977, [115] Vila-Gispert et al. 2007, [116] Vinyoles et al. 2007, [117] Waters et al. 2002, [118] Welcomme 1988, [119] Witkowski 2006, [121] Zambrano 2003, [122] Zambrano & Hinojosa 1999, [123] Zambrano & Macias-García 2000, [124] Zambrano et al. 1999