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Review

The cost of non-native aquatic species introductions in Spain: fact or fiction?

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Abstract

The ecological and economic impact of non-native species introduction on local native biodiversity is often reported as undeniable scientific evidence on which to base management and sound policy. Here I used a combination of databases (Fishbase, FAO and IMPASSE) and an extensive review of existing literature to establish the proportion of non-native aquatic species introductions in Spain that are responsible for ecological and economic impacts. In Spain, aquaculture and angling are the two main ecosystem services responsible for introduction of non-native aquatic species. In total, forty two percent of all non-native aquatic introductions are intentional. Very little ecological impact resulting from these non-native species introductions has been demonstrated with some representing a benefit to Spanish ecosystem services. In 2007, the economic benefits to Spanish aquaculture arising from non-native aquatic species (n=9) was close to €46.73 million (about U.S. $69 million) annually for an estimated average ecological risk for all introductions of 16.5% (SD= 26.85). These results must be seen in the context of other environmental factors such as habitat destruction, water abstraction and pollution from agricultural farming which represent major environmental pressures on Spanish aquatic fauna.

Key words: alien fish, aquaculture, biodiversity, economic value, ecological impact

Introduction

Like many Mediterranean countries, in the last 30 years Spain has seen the demand and pressure on water rocketing (Anonymous 2005, 2006, 2007). These water abstractions for irrigation of agricultural land, golf courses or supply of disproportionate urban development, underpin a rapid growth in the national and regional economy. According to the Spanish Ministry for the Environment, there are 510,000 illegal wells in Spain (Anonymous 2006). The main ecological impacts of such unregulated water abstraction have been the decline of wetland ecosystems, changes in land use, as well as the deterioration of water quality (Marchetti et al. 2006; Light and Marchetti 2007). In addition to deterioration of physical habitat and its direct consequences on native biotic fauna, increasingly, existing communities are modified by the introduction of non-native species (Elvira and Almodovar 2001; Rodriguez et al. 2005; Orizaola and Brana 2006). However, due to the magnitude of physical habitat changes, it remains difficult to determine if aquatic non-native species are the driver of biodiversity changes or only passengers (Brown 2007; Didham et al. 2005; Sagoff 2005, 2007). For the same reasons, it is difficult to precisely characterise the non-native species contribution to both ecological and economic costs (Marchetti et al. 2004; Marchetti et al. 2006; Light and Marchetti 2007).

Worldwide, the ecological impacts arising from non-native fish species have rarely been demonstrated contrarily to an established idea that non-native fish are necessarily the cause of ecological disruptions if not of ecological impact (Gozlan 2008; Gozlan 2009; Gozlan and Newton 2009; Brown 2007; Didham et al. 2005; Sagoff 2005, 2007). However, it is worth noting that in some cases potential impacts of most non-native fish species are unknown due to geographical and taxonomic bias (Gherardi 2007).

Aquaculture and sport fishing, the main drivers for aquatic non-native species introduction (Gozlan et al. 2010a, 2010b) are rapidly expanding worldwide and will continue to grow as a response to over-exploitation of wild fish stocks as currently major fisheries are commercially unsustainable and many others are on the verge of extinction (Pontecorvo and Schrank 2009). In order to grow, aquaculture will have to rely on market diversification and as such on the farming of new species likely to be non-native ones. Here the community of non-native aquatic species introduced in Spain is analysed in terms of ecological impacts and economic benefits and perspectives are drawn on the future need/cost of non-native introductions in Spain.

The aim of this study is to 1) quantify the number and type of non-native aquatic species introduced in Spain, 2) to characterise the probability of ecological impacts associated with these species, 3) to evaluate the importance of these species for the Spanish economy in line with species potential for ecological impacts.

Datasets

Open access and independently collected databases were used to characterise the pattern of non-native aquatic species introductions in Spain. I used a combination of datasets on species introductions related to aquaculture and stock-enhancement activities (IMPASSE Database), Spanish aquaculture production (Food and Agriculture Organisation FAO; http://www.fao.org/fi/statist/statit.asp) and on world species introduction (FishBase http://www.fishbase.org, SealifeBase http://www.sealifebase.org and Global Invasive Species Database http://www.issg.org/database/welcome/) all accessed on 01/10/09. The IMPASSE Database was built during the course of the IMPASSE project [Environmental impacts of alien species in aquaculture (IMPASSE) Coordination Action Priority FP6 2005-SSP-5A Sustainable management of Europe's Natural Resources Project no.: 044142] and consists of a collation of information from a panel of European experts on non-native species, source of introduction, pathways and ecological and economic impact for 41 European countries. The FAO dataset used contained statistics on aquaculture production, volume and value price per kilogram per species, for a time series of 57. years ending with the latest year for which statistics are available in the database (i.e. 2007). Here aquaculture production includes fish, crustaceans, shellfish and algae. Species names which could not confidently be linked to a Latin name were eliminated. For the remaining 16 species, family, introduction status and confirmed ecological impact were obtained from scientific peered reviewed publications.

In this study, a non-native species was referred to as a single species introduction from outside national boundaries, not from trans-locations within Spain. No measure of propagule pressure at country level is provided (number/volume of repeated introductions within the same country) but volumes of production for non-native farmed species are provided. Here I followed the European community definition of ecological impact derived from Gozlan (2008) where only negative impacts on native ecosystems are considered. It is measured through peer reviewed publication of ecological impact defined as a quantifiable impact resulting in habitat degradation, competition with native species for spawning ground, hybridisation threatening species integrity and/or predation on native species populations resulting in their decline. In this way, over at least a 57 year period, it is assumed that an undisputed ecological impact arising from aquatic species introduction would have been picked up in scientific literature.

Human pressure on Spanish aquatic ecosystems

In the last decades, the changes in land use and water demand that have affected Spanish society have resulted in a deep modification of aquatic ecosystems (Table 1). For example, according to a recent report (Anonymous 2006), there are 510,000 illegal wells in Spain accounting for about the average water consumption of 58 million people (i.e 3600 hm^3). Such drastic changes over a relatively limited period of time have clear consequences on the structure of aquatic community as well as the associated ecosystem function. In this context, other potential for additional ecological impacts, such as the introduction of non-native species, are difficult to measure (Light and Marchetti 2007). Most non-native aquatic species introduced (n=105) are fish species (36%) followed by algae (16%), crustaceans (14%), parasites of aquatic hosts (14%), gastropods (12%) bivalves (7%) and fungi (1%). Overall, forty two percent of all non-native aquatic introductions are intentional (n=60) with the majority of accidental non-target

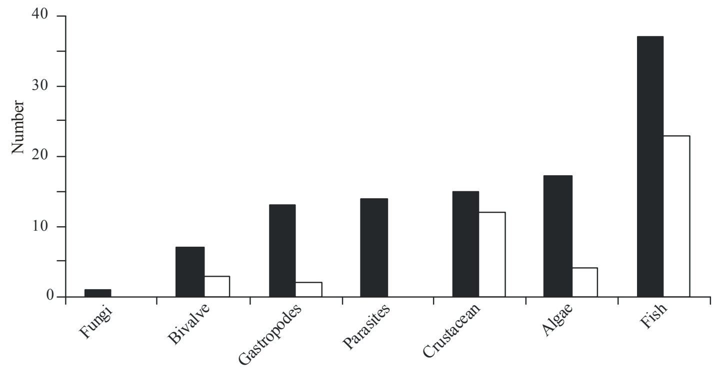

Figure 1. Total number of non-native aquatic species (or aquatic hosts) introduced in Spain until 2010 per given group (black bars) and proportion of intentional introduction (white bars) is given.

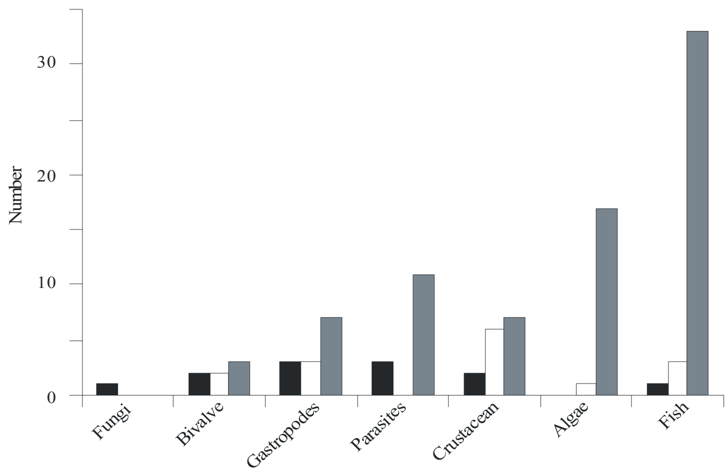

Figure 2. Breakdown of number of species associated to a negative ecological (black) and/or positive ecosystem service (white) impact reported for each group of non-native aquatic species introduced in Spain until 2010. Unknown are represented in grey.

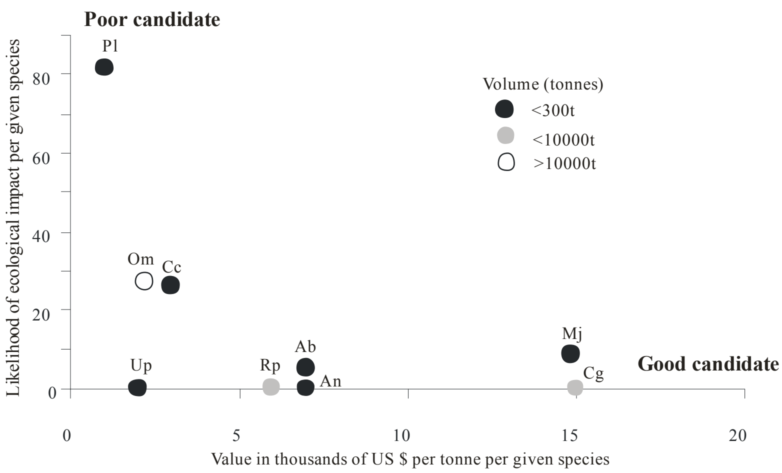

Figure 3. Relationship between economic value and likelihood of ecological impact given non-native species used in Spanish aquaculture. Species names are Ab *Acipenser baerii*, An *Acipenser naccarii*, Cc *Cyprinus carpio*, Cg *Crassostrea gigas*, Mj *Marsupenaeus japonicus*, Om *Oncorhynchus mykiss*, Pl *Pacifastacus leniusculus*, Rp *Ruditapes philippinarum*, Up *Undaria pinnatifida*. White circles indicate species production in tonnes strictly above 10,000; grey circles indicate more than 300 and less than 10,000 and black circles indicate strictly less than 300.

Table 1. Estimates of illegal anthropogenic pressure on water abstraction in various Spanish River basins.

River Basin	Water abstractiont	Reference
Upper Guadiana River Basin	- 22,000 illegal wells; - Since 1987, irrigation farms overexploit the aquifer by 70% (i.e. 54.1 hm^3)	Anonymous (2005)
Guadalquivir River Basin	- 10,000 wells are illegal	Anonymous (2006).
Segura river basin	- Between 1990 and 2000, illegally irrigated areas increased at a rate of 6,500 ha/year - Between 1981 and 2006, in the Águilas region the number of hectares farmed under plastic has tripled	Anonymous (2007)
Tagus River Basin	- In the Comunidad de Madrid, there are 4.2 times more illegal wells than authorized ones (i.e. 70 hm^3/year)	El País. 20-09-2005 in Anonymous (2005)
Catalan Water Agency	- In Catalonia there are around four times more illegal groundwater abstractions than legal ones	El Periódico de Catalunya, 18-2-2006 in Anonymous (2006)

species introductions illustrated by parasites and fungi (24%), gastropods (18%) and bivalves (7%) (Figure 1). In Spain, the trend in non-native aquatic species introduction shows that most introductions are intentional, mainly in support of existing aquatic ecosystem services such as aquaculture and sport fishing (Elvira and Almodovar 2001). This is particularly true for fish and crustacean introductions for which the majority are intentional and for which species are integral parts of the Spanish aquaculture portfolio (See Annex 1, Figure 1).

Ecological impact resulting from non-native species

Overall very little ecological impact resulting from these non-native species introductions has been demonstrated with some representing a benefit to Spanish ecosystem services (Figure 2). For example, the economic benefits to Spanish aquaculture arising from non-native aquatic species (n=9) is close to €46.73 million (about U.S. $69 million) annually for an estimated average ecological risk for all introductions of 16.5% (SD= 26.85). It is now apparent for non-native species introduced to Spain that the more introductions occur, the greater the chance of associated ecological impacts (n=105, Pearson correlation 0.96, P<0.01). However, our capacity to quantify the true value of individual species likely ecological impact remains limited (Hermoso et al. 2009; Rincón et al. 1990, 2002). Out of the 37 fish species introduced to Spain, 31 are freshwater species with the greatest potential for ecological impact attributed to black bullhead *Ameiurus melas* (Rafinesque, 1820) (42 % of all introductions worldwide, n=21) followed by topmouth gudgeon *Pseudorasbora parva* (Temminck and Schlegel, 1846) (37% of all introductions worldwide, n=35).

Recently Williamson's rule of ten stating that ten percent of all introductions will become invasive and that ten percent of these invasive species will cause an ecological impact (Williamson 1996) has been reinforced for non-native freshwater fish introduced worldwide (Gozlan 2008). This gives rise to the most common comment about the vast level of unknown (see Figure 2) and the associated risk of underestimating the true level of ecological impact resulting from non-native aquatic species introductions. This concern raises two key points: 1) there is an urgent effort to be made in the field of biological invasion to characterise the true impact of non-native species introduction (i.e. significant decline of native biodiversity, a loss of genetic integrity or/and a change in ecosystem function; see Gozlan 2008 for a full definition); 2) If after an extensive period of time (to be define by the various stakeholders) there is no obvious ecological impact associated with the introduction of non-native species then one could argue that either there is no impact or if there is one, then it is very mild and should be assessed in a wider perspective of biodiversity conservation.

Perspectives

Other more serious ecological impacts resulting from other ecosystem services such as sea fisheries, may force European countries to put the risk of non-native introduction from aquaculture into perspective with stock decline of wild populations (Pontecorvo and Schrank 2009). The need to release the pressure on wild stocks may in the future also drive individual countries to rely on an enlarged portfolio of aquaculture with emphasis on herbivore species, at the same time increasing reliance on non-native species. Rainbow trout *Oncorhynchus mykiss* (Walbaum, 1792) is a good example of a species which has been introduced worldwide for its farming potential and following an increased consumer demand despite a high risk of ecological impact on native salmonid populations (Bartholomew and Reno 2002; McDowall 2006; Buria et al. 2007; Fausch 2007). Other species such as *A. melas*, *Procambarus clarkii* (Girard, 1852) or *P. parva* have also been introduced via an aquaculture pathway and have been reported to cause ecological impacts on native fauna through disease introduction (Gozlan et al. 2005, 2006, 2010b) and/or direct competition (Rodriguez et al. 2005; Musil et al. 2008) but with not associated benefits to any ecosystem services. If policy makers were to put the cost of any ecological impact resulting from a non-native species introduction (Britton and Brazier, 2006) back to the entity responsible for that introduction, in a similar way as is done for chemical pollution, then sport fishing and the aquaculture industry would look closely at the ratio between financial benefit and risk of biological pollution (Gozlan and Newton 2009) (Figure 3).

Finally, the need for further science based evidence of the relationship between non-native species introduction and ecological impact are urgently needed in order to put in place sound and reliable risk assessments (Gozlan et al. 2010a; Copp et al. 2009).

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Annex 1. List of non-native aquatic species (or aquatic hosts) introduced to Spain. Data extracted from IMPASSE data base and completed with literature review. * indicates species which were omitted from analysis. Abbreviations are as follow: A= aquaculture/farming/fisheries, S = sport fishing, At = Aquarium trade, B = biological control, N = natural dispersal and H = intentional human introduction.

Species scientific name	Taxonomic group/Species common name	Ecosystem service/pathway
Asparagopsis armata	Algae	*-/N*
Caulerpa taxifolia (Vahl) C. Ag.	Algae/Caulerpa	*At/N*
Codium fragile ssp. *tomentosoides* (van Goor) P.C. Silva	Algae/Dead man's fingers	*-/N*
Colpomenia peregrina Sauv.	Algae/Oyster thief	*-/N*
Didymorphenia geminata (Lyngbye) M. Schmidt	Algae	*-/N*
Fucus spiralis	Algae/Spiral Wrack	*-/N*
Grateloupia filicina var. *Luxurians* A. and E.S. Gepp	Algae	*-/N*
Grateloupia lanceolata (Okamura) Kawaguchi	Algae	*-/N*
Grateloupia turuturu Yamada	Algae	*-/N*
Heterosiphonia japonica Yendo, K	Algae	*-/N*
Hypnea spinella Kuetzing	Algae	*-/N*
Lophocladia lallemandii (Montagne) F.Schmitz	Algae	*-/N*
Neosiphonia harveyi (J.W.Bailey)	Algae	*-/N*
Sargassum muticum Yendo	Algae/ Wireweed	*-/N*
Scytosiphon dotyi Wynne	Algae/ Scytosiphon	*-/N*
Undaria pinnatifida (Harvey) Suringar	Algae/ Wakame	*A/H*
Elodea canadensis Michx	Algae (angiosperm)/ Pondweed	*At/H*
Chlamys lischkei Dunker, 1850	Bivalve/ Scallop	*A/H*
Corbicula fluminea Müller, 1774	Bivalve/Asian clam	*A/H*
Crassostrea gigas Thunberg, 1793	Bivalve/Pacific oyster	*A/H*
Dreissena polymorpha Pallas, 1771	Bivalve/Zebra mussel	*-/H*
Mytilopsis leucophaeta Conrad, 1831	Bivalve/Conrad's false mussel	*A/H*
Ruditapes philippinarum Adams & Reeve, 1850	Bivalve/Japanese carpet shell	*A/H*
Xenostrobus secures Lamarck, 1819	Bivalve/Black-pygmy mussel	*A/H*
Craspedacusta sowerbii Lankester, 1880	Cnidaria	*-/H*
Artemia franciscana Kellogg, 1906	Crustacean	*A,At/H*
Astacus astacus Linnaeus, 1758	Crustacean/Noble Crayfish	*A/H*
Astacus leptodactylus Eschscholtz, 1823	Crustacean/Galician Crayfish	*A/H*
Calappa pelii Herklots, 1851	Crustacean/Spiny box crab	*-/N*
Cherax destructor Clark, 1936	Crustacean/Yabby	*A/H*
Cherax quadricarinatus Von Martens, 1868	Crustacean/Redclaw Crayfish	*A/H*
Cryptosoma cristatum Brullé, 1837	Crustacean	*-/N*
Dolerocyris simensis	Crustacean	*-/-*
Eriocheir sinensis Edwards, 1853	Crustacean/Chinese Mitten Crab	*A/H*
Lernea cyprinacea Linnaeus, 1758	Crustacean	*A/Ac*
Marsupenaeus japonicus Bate, 1888	Crustacean/Kuruma shrimp	*A/H*
Pacifastacus leniusculus Dana, 1852	Crustacean/Signal crayfish	*A/H*
Palaemon macrodactylus Rathbun, 1902	Crustacean/Oriental shrimp	*A/H*
Percnon gibbesi Edwards, 1853	Crustacean/Sally Lightfoot	*-/N*
Procambarus clarkii Girard, 1852	Crustacean/Red swamp crayfish	*A/H*
Procambarus zonangulus Hobbs, Jr. and Hobbs III, 1990	Crustacean/White river crayfish	*A/H*
Rhithropanopeus harrisii Gould, 1841	Crustacean/Harris mud crab	*A/H*
Scyllarus posteli Forest, 1963	Crustacean/Slipper lobster	*A/H*
Abramis brama Forest, 1963	Fish/Common bream	*S/H*
Acipenser baerii Linnaeus, 1758	Fish/Siberian sturgeon	*A/H*
Acipenser naccarii Bonaparte, 1836	Fish/Adriatic sturgeon	*A/H*
Alburnus alburnus Linnaeus, 1758	Fish/Bleak	*S/H*
Ameiurus melas Rafinesque, 1820	Fish/Black bullhead	*S/H*
Ameiurus nebulosus Lesueur, 1819	Fish/Brown bullhead	*S/H*
Aphanius fasciatus Valenciennes, 1821	Fish/European Toothcarp	*At/H*
Aristichthys nobilis Agassiz, 1831	Fish/Bighead carp	*A/H*
Astronotus ocellatus Agassiz, 1831	Fish/Oscar	*At/H*
Australoheros facetus (Jenyns, 1842)	Fish/Chameleon cichlid	*At/H*
Blicca bjoerkna Linnaeus, 1758	Fish/White bream	*S/H*
Carassius auratus Linnaeus, 1758	Fish/Goldfish	*At/H*

Annex 1. (continued)

Species scientific name	Taxonomic group/Species common name	Ecosystem service/pathway
Cobitis bilineata Canestrini, 1865	Fish	*-/H*
Ctenopharyngodon idella Valenciennes, 1844	Fish/Grass carp	*A/H*
Cyprinus carpio Linnaeus, 1758	Fish/Common carp	*A,S/H*
Esox lucius Linnaeus, 1758	Fish/Pike	*S/H*
Fistularia petimba Lacepède, 1803	Fish/Red cornetfish	*-/N*
Fundulus heteroclitus Linnaeus, 1766	Fish/Mummichog	*B, At/H*
Gambusia affinis (Baird and Girard, 1853)	Fish/Mosquitofish	*B/H*
Gambusia holbrooki Girard, 1859	Fish/Eastern mosquitofish	*B/H*
Gobio gobio Linnaeus, 1758	Fish/Gudgeon	*S/H*
Hucho hucho Linnaeus, 1758	Fish/Huchen	*A/H*
Ictalurus punctatus Rafinesque, 1818	Fish/Channel catfish	*S/H*
Lepomis gibbosus Linnaeus, 1758	Fish/Pumkinseed	*At/H*
Micropterus salmoides Lacepède, 1802	Fish/Black bass	*S/H*
Oncorhynchus kisutch Walbaum, 1792	Fish/Coho salmon	*A/H*
Oncorhynchus mykiss Walbaum, 1792	Fish/Rainbow trout	*A/H*
Perca fluviatilis Linnaeus, 1758	Fish/Perch	*S/H*
Piaractus brachypomus Cuvier, 1817	Fish/Piranas	*At/H*
Poecilia reticulata Peters, 1859	Fish/Guppy	*At/H*
Psenes pellucidus Lütken, 1880	Fish/Bluefin driftfish	*A/N*
Pseudorasbor parva Temminck and Schlegel, 1846	Fish/Topmouth gudgeon	*-/A*
Rutilus rutilus Linnaeus, 1758	Fish/Roach	*S/H*
Salvelinus fontinalis Mitchill, 1814	Fish/Brook trout	*A,S/H*
Sander lucioperca Linnaeus, 1758	Fish/Zander	*S/H*
Scardinius erythrophthalmus (Linnaeus, 1758)	Fish/Rudd	*S/H*
Seriola fasciata Bloch, 1793	Fish/Lesser amberjack	*S/H*
Silurus glanis Linnaeus, 1758	Fish/Wels catfish	*S/H*
Aphanomyces astaci Schikora	Fungi	*-/Ac*
Crepidula aculeata Gmelin, 1791	Gastropod	*-/Ac*
Crepidula fornicata Linnaeus, 1758	Gastropod	*-/Ac*
Cyclope neritea Linnaeus, C., 1758	Gastropod	*-/Ac*
Ferrissia wautieri (Mirolli, 1960)	Gastropod	*-/Ac*
Gibbula albida Gmelin, J.F., 1791	Gastropod	*-/Ac*
Gyraulus chinensis Dunker, 1848	Gastropod	*-/Ac*
Haminoea callidegenita Gibson and Chia, 1989	Gastropod	*-/Ac*
Helisoma duryi (Wetherby, 1879)	Gastropod	*-/Ac*
Melanoides tuberculata Müller, 1774	Gastropod	*-/Ac*
Physella acuta Draparnaud, 1805	Gastropod	*-/Ac*
Pomacea canaliculata Lamarck, 1828	Mollusc	*-/Ac*
Potamopyrgus antipodarum Gray, 1853	Gastropod	*-/Ac*
Pseudosuccinea columella Say, 1817	Gastropod	*-/Ac*
Myocastor coypus Molina, 1782	Mammal	*-A/H*
Ondatra zibethicus Linnaeus, 1766	Mammal	*-A/H*
Psysella acuta Draparnaud, 1805	Mollusc	*-/Ac*
Anguillicolla crassus (Kuwahara, Niimi & Hagaki, 1974)	Parasite (fish)	*-/Ac*
Argulus japonicus Thiele, 1900	Parasite (fish)/ Argulus	*-/Ac*
Bothriocephalus acheilognathi Yamaguti, 1934	Parasite (fish)/ Asian tapeworm	*-/Ac*
Dactylogyrus anchoratus (Duj., 1845)	Parasite (fish)	*-/Ac*
Gyrodactylus cyprini Diarova, 1964	Parasite (fish)	*-/Ac*
Gyrodactylus katharineri Malmberg, 1964	Parasite (fish)	*-/Ac*
Gyrodactylus salaris Malmberg, 1957	Parasite (fish)	*-/Ac*
Lernaea cyprinacea Linnaeus, 1758	Parasite (fish)	*-/Ac*
Phyllodistomum folium (Olfers, 1816)	Parasite (fish)	*-/Ac*
Pseudodactylogyrus anguillae Yin and Sproston, 1948	Parasite (fish)	*-/Ac*
Pseudodactylogyrus bini (Kikuchi, 1929)	Parasite (fish)	*-/Ac*
Bonamia ostreae	Parasite (shells)	*-/Ac*
Marteilia refringens (Grizel et al. 1974)	Parasite (shells)	*-/Ac*
Xironogiton victoriensis Gelder and Hall, 1990	Parasite(crustacean)	*-/Ac*
Dugesia (Girardia) tigrina Girard**,** 1850	*Plathelminth	*-/Ac*