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Global documentation of fish introductions: the growing crisis and recommendations for action

Christine Marie V. Casal
WorldFish Center, Philippine Office, Khush Hall, IRRI College, Los Baños, Laguna 4031, Philippines; (e-mail: c.casal@cgiar.org; fax: 63 49 536 0202)

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Abstract

Fish provides 15% of the total animal protein in human diets. It is also the primary source of livelihood for 35 million people (30 M in Asia and 2.6 M in Africa). The increase in global population and demand for fish protein cannot be met by capture fisheries alone. Governments are turning towards aquaculture as the source of fish protein. However, it has also led to the introduction and establishment of non-native species in local ecosystems through their escapement from aquaculture facilities to the wild. In freshwater ecosystems with relatively high endemism, this has become a significant problem. Documenting the international movement of fish is one way of providing a general view of the magnitude of these movements and the existing and potential threat faced by ecosystems due to species invasiveness. Information, however, is limited and scattered in different journals and agency/project reports. Several agencies, both local and international, have databases that provide information on invasive species (terrestrial and aquatic, local, regional or international in scope). The critical challenge is for consolidation, common access through data sharing and development of risk assessment and management tools. This is proposed through the use of Internet technology, sharing of databases or having a gateway or portal to which all introduced and invasive fish species related databases link. The fusion of these information sources will allow access to updated and reliable information. The experience of the WorldFish Center in documenting these phenomena through developing the FishBase information system and global partnerships is presented with recommendations for harmonizing approaches.

Introduction

The importance of fish in the lives of people all over the world cannot be overemphasized. Aside from providing 15% of the total animal protein in human diets, it is also the primary source of livelihood for 35 million people (30 M in Asia and 2.6 M in Africa) (FAO 2002). It is one of the major sources of livelihood and food for people from the developing world.

The increase in global population and demand for fish protein cannot be met by capture fisheries alone. Governments are turning towards aquaculture as the source of fish and general protein and unlike capture fisheries, a significant increase in aquaculture production has been observed.

In 2000, global aquaculture production provided 45.7 million tonnes by weight and US$56.5 billion by value (more than half of which were finfish) (FAO 2002). The aquaculture industry has also promoted the introduction of 'aquaculture species' worldwide. Whilst they contributed significantly to aquaculture production (Bartley and Casal 1998), it has also led to the introduction and establishment of these "aquaculture species" in local ecosystems through their escapement to the wild. In freshwater ecosystems with relatively high endemism it has become a significant problem. The tilapia *Oreochromis niloticus* has been introduced into 88 countries and established in aquaculture in 51 (FishBase 2003). Global freshwater aquaculture production of *O. niloticus* is 904,848 mt (FISHSTAT 2003). However, it may have played a significant role in the extinction of endemic cyprinids in Lake Lanao (Bleher 1994) as well as contributing to driving the endemic sinarapan (*Mistichthys luzonensis*) to the verge of extinction in Lake Buhi, Philippines (Maguilas, 1999). Sinarapan is a delicacy and of great economic importance to the communities around the lake. It is listed in the Guinness Book of World Records as 'smallest food fish' (Foot 2000).

Aquaculture has been used as an example to illustrate the growing crisis of the introduction and establishment of non-native species. It is the major reason for introducing species. Several countries rely on introduced species for aquaculture, and the increasing demand for food will definitely promote the continuing introduction of non-native species and their improved strains for aquaculture.

The magnitude of aquaculture production in Asia, a significant proportion of which is contributed by introduced species, may produce both favorable and detrimental results. It has definitely contributed significantly to increased freshwater aquaculture production in the region. However, the widespread introduction of species may pose significant ecological implications. These include the incorporation of species, which may be in direct or indirect competition to endemic or native species in Asia's freshwater ecosystems. Tilapias have been implicated in the depletion and/or extinction of goby (*Gobiopterus lacustris*) in Laguna de Bay, (*Sardinella tawilis*) in Taal Lake, (*Mistichthys luzonensis*) in Lakes Buhi and Bato and small endemic cyprinids in Lake Sebu in the Philippines (Pullin et al. 1997).

Aquaculture is the major reason for introducing fish species to different countries. Of the 1205 introduction records for aquaculture purposes, 607 (50%) are reported as having been established in the wild, 421 (35%) are reported as not established and 177 (15%) with unknown establishment. In Asia, there have been 406 introduction records, 176 (43.3%) are reported as having been established in the wild, 152 (37.4%) are reported as not established and 78 (19.2%) with unknown establishment (FishBase 2003).

Documenting global introductions

Initiatives on documenting global fish introductions have been undertaken by the Food and Agriculture Organization (Database of Introduced Aquatic Species – DIAS) of the United Nations and FishBase which has been developed at the WorldFish Center.

FishBase is a biological information system on finfish being developed at the WorldFish Center Philippine office in collaboration with other FishBase Consortium members namely the Food and Agriculture Organization (Rome, Italy), Fisheries Centre, University of British Columbia (Canada), Musée Royal de l'Afrique Centrale (Tervuren, Belgium), Swedish Museum of Natural History (Stockholm, Sweden), Institut für Meereskunde (Kiel, Germany) and the Muséum National d'Histoire Naturelle (Paris, France). Other important partners include the California Academy of Sciences, Eschmeyer's Catalog of Fishes, FAO Databases (SIDP, FIGIS, Catches, Aquaculture, Introductions), IUCN's Red List, National Fish Databases, Genbank, Ecotoxicology Bibliographies (ZR, NISC, ASFA) and various databases (Brains, Ciguatera, Oxygen, Recruitment). This started as an ICLARM software project in 1988, which was initially projected to contain biological information, identification keys and morphometric data for 200 major fish species with the ultimate goal of 2500 species (Froese and Pauly 2000). FishBase now contains over 28,500 of the estimated 30,000 species. All entries in the database are referenced, with sources ranging from peer-reviewed publications, reports from government line agencies and projects and personal communication with taxonomic, fisheries, biological and country experts. Encoding of information is done by the FishBase project team in the Philippines and FishBase staff based in the offices of other consortium members. It is available in CD, DVD and online (http://www.fishbase.org).

- > 28,500 fish species (and associated biology) with > 79,700 synonyms
- > 188,300 common names in 240 languages
- > 158,700 country records with links to ~400 ecosystems
- > 1.8 M geo-referenced records (39 museums; 23,854 species)
- > 11,500 morphology records
- > 38,800 fish images and photos
- > 33,200 bibliographic citations
- > 500 journals linked on-line
- > 4.48 million record database (2 Gb; 180 database tables)
- Book available in 5 languages (English, Spanish, French, Portuguese and Chinese)
- Multi-language (11) on-line access (Main Pages)
- 16 Non-roman scripts for common names

At present, there are 3072 reported fish introductions (between countries) in FishBase. These represent 568 species from 104 families. Most of these introductions (2904) are in freshwater ecosystems (Figure 1). About 59% (1805) of global introductions are reported as established in the wild, with over 54% (1674) being in freshwater. Aquaculture has been cited as the main reason for introducing finfish into freshwater systems with 1205 (40%) of the documented introduction records (FishBase 2003) highlighting the significance of movement of exotic species for aquaculture.

Information in global introductions in FishBase was based on data from DIAS and over 200 publications. However, this database is limited to documenting the initial introduction of a species into countries, subsequent introductions as well as the magnitude of the introductions and translocations are included as comments (Casal and Bartley 2000). There are, however, introductions that have gone unreported while documented reports need status updates. The establishment in the wild is unknown for 491 records. Ecological (81.5%) and socioeconomic (79%) impacts are also unknown for most of the records.

Research and information gaps are widening. Species have been reported to occur in their

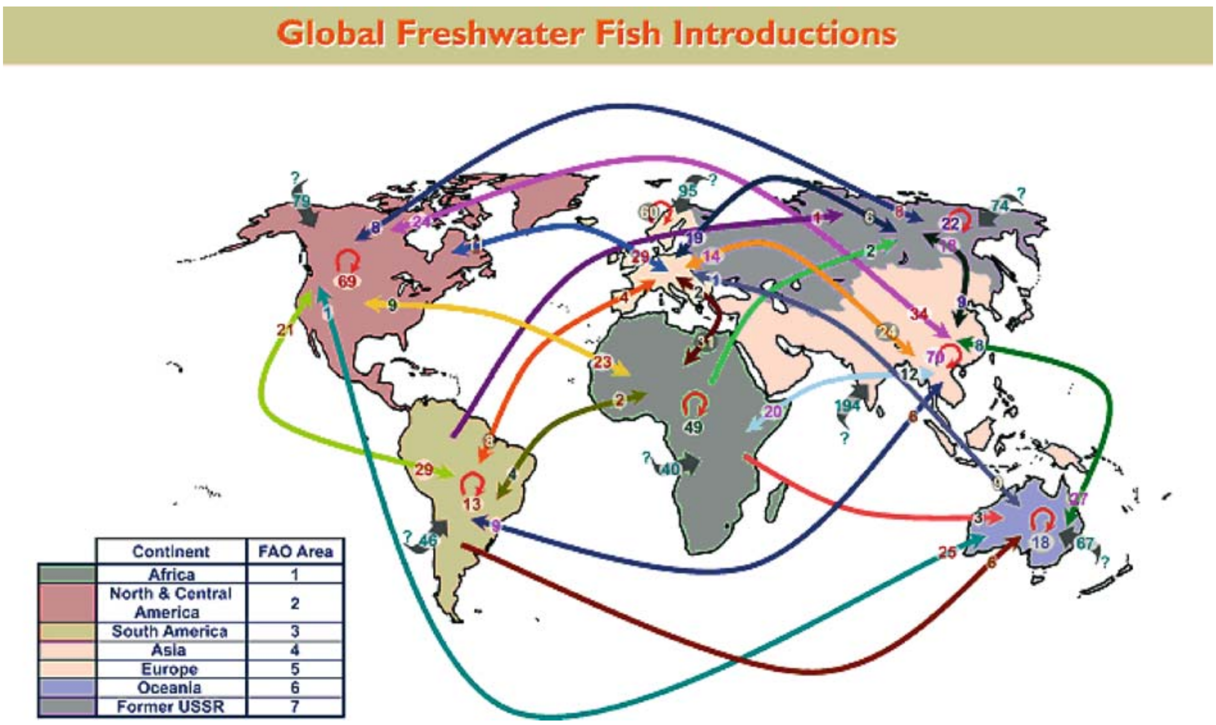

Figure 1. Global freshwater fish introductions.

non-native distributional range without prior records of their introduction (*Carassius auratus* has been reported in inland waters of Samoa, date, source nor reason of introduction is unknown (Welcomme 1988)). A small population of *Parachromis managuensis* was established in the Quarry Pond on the University of Hawaii Campus; occasionally, specimens are also taken in Mânoa Stream, date, source nor reason of introduction is unknown (Yamamoto and Tagawa 2000). There are also old reports of species being introduced into countries or lakes without any updates of their continued presence or establishment, their impact to native or endemic species or their socioeconomic contributions. However, absence of evidence is not evidence of absence: there may be inaccessible published reports or unpublished reports in various institutions and the information in these needs to be included in DIAS and FishBase.

What can databases do?

Biological invasions are considered to be the second most important cause of species extinction after habitat destruction (Vitousek et al. 1997). It is therefore imperative that caution be practiced in introducing exotic species to any country. Precautionary approaches to species introductions (FAO 1996), which may eventually lead to biological invasions have been in the forefront of discussions in several national, regional and international fora.

> *"In relation to aquaculture, experience has shown that animals will usually escape the confines of a facility. As a consequence, the introduction of aquatic organisms for aquaculture should be considered as a purposeful introduction into the wild, even though the quarantine/hatchery facility may be a closed system."* (FAO 1996)

Based on information within FishBase, 47% of recorded fishes introduced for aquaculture have established themselves in the wild. This is significant considering that several developing countries with significant aquaculture activities do not have sufficient resources to monitor the faunal changes in their natural waters.

Lever (1996) notes: *"More careful examination of case histories of the introduction of individual species and their behavior and ecology in their natural range, could help to determine whether short-term gain should be sacrificed for the sake of long-term ecological and socio-economic stability."*

A review of a species ecology in its natural range would provide individuals or governments planning to introduce the species, its salinity and temperature tolerances. This would also present the range of food the species can eat in order to survive and reproduce. Furthermore, life history information would offer growth rates, maturity and several other data to imply resilience of a species when introduced in a similar ecosystem. This information would provide clues to the invasive potential of a species.

The ICES Code of Practice on the Introduction and Transfer of Marine Organisms (ICES 1995) describes research activities that should be conducted prior to any introduction:

- Desk assessment of the biology and ecology of the intended introduction
- Preparation of a hazard assessment (detailed analysis of potential environmental impacts);
- Examination of the species within its home range.

Biological information is available from a wide range of current and historical sources to contribute to such studies. These however may not be easily available to the researchers, especially scientists from developing countries who more often than not, do not have access to these data sources. Customizable biological databases like FishBase can therefore be of significant use in these conditions. 'Fields' deemed necessary by invasive biology experts should be incorporated in these databases as well as collaborator researchers from different countries and institutions will be encouraged to contribute, critique and incorporate data in the database.

FishBase is a relational database on Microsoft Access format. It holds information in over 180 databases in a wide range of topics like environment, reproduction, food items, maximum lengths, temperature ranges, information on introduction of species, their impacts and establishment in the wild and much more. These tables can be linked through a common field which may be a species code. Thus, all of the information 180 databases (tables) can be linked to a species.

The preparation of risk assessments must include examination of the impact of species in countries to which they have been introduced. Databases like the Database of Introduced Aquatic Species (DIAS), Global Invasive Species Database (GISD), Non Indigenous Species Database (NISD), Database on Alien Species in the Baltic Sea, CIESM Atlas of Exotic Species in the Mediterranean and FishBase, among others, are resources that could be tapped for this. Table 1 demonstrates an example of a FishBase generated report listing species with adverse ecological effects after the introduction to a number of countries.

Table 1 identifies the 18 species with the most reported adverse ecological impacts, the number of countries they have been introduced to and the number of countries with reports on their establishment in the wild. Thirteen of the species listed are used in commercial aquaculture. This type of report can quickly warn researchers and natural resource managers that caution should be undertaken in the introduction of particular species. The experiences of the countries where the particular species has been introduced can be further investigated to learn from their experiences. In 40% of the introductions reported, aquaculture has been mentioned as the reason behind the movement of species across borders. Of the top ten freshwater aquaculture species in 2000 (FAO 2002), four (*Hypophthalmichthys molitrix, Ctenopharyngodon idellus, Cyprinus carpio carpio and Oreochromis niloticus niloticus*) led to adverse ecological effects in countries where they were introduced (FishBase 2003). Details are in Table 2.

Having seamless linkages among databases would maximize the utility of the information within any one database. For example, for a particular species, information from global, regional and national databases can be linked to allow users to browse on available data for that particular species, taking in general to detailed information as well as consulting original references which were utilized. What is present in FishBase at the moment is a species-species linkage to several databases. An example of a species-species database linkage is through the species profile of *Gadus morhua* in FishBase (http://www.fishbase.org./Summary/SpeciesSummary.cfm?ID = 69 &genusname = Gadusid = 8049&1v1 = 3& srchmode = 1) on the species from the National Center for Biotechnology Information (NCBI) and so much more. For the seamless species database, I am proposing that through access of a species profile in a common portal, information for a species from different sites will be provided in one single page (highlighting providers of data per field).

Table 3 presents the top ten countries contributing to global freshwater aquaculture production. The table has been generated through a combination of FISHSTAT and FishBase. Aquaculture species in FISHSTAT have been assigned country status generated from FishBase. Where country status was not clear (in some production statistics only families or genera were provided), values were placed under the uncertain column. The table highlights the contribution of freshwater aquaculture production and emphasizes the heavy reliance on introduced species of these countries. On the average, 11% of the production of these countries is from introduced species with values ranging from 87% in Brazil to 0% in Myanmar.

The over 2.35 M metric tonnes (13% of total) contributed by introduced finfish species to freshwater aquaculture production in 2000 (FAO 2002), encourage countries to utilize exotic species in their national aquaculture programs.

Eight of the top ten producing countries are Asian, where people are heavily dependent on fish. The relatively high percentage of reliance on introduced species in most cited Asian countries is disturbing since this could be an indicator of the degree of infiltration of these exotics. Non-native species used in aquaculture often escape from aquaculture facilities to open waters (Welcomme 1988). Hence, the premise behind the precautionary approach in evaluating non-native species for aquaculture is that ultimately species will escape to the wild. The information can therefore be used not only to present the socio-economic importance of non-native species in aquaculture in these countries, but also as an indicator for current or potential environmental hotspots of freshwater ecosystems in these countries. The usage of non-native species for

Table 1. Top 18 species with adverse ecological impacts.

Species	Number of countries where species have been introduced	Number of countries reporting			Percentage	
		Establishment	No establishment	Adverse ecological effect	Establishment	Adverse ecological reports
*Cyprinus carpio carpio**	121	91	9	15	75.2	12.4
*Oreochromis mossambicus**	90	73	13	13	81.1	14.4
*Oreochromis niloticus**	85	49	15	12	57.7	14.1
*Oncorhynchus mykiss**	90	69	17	10	76.7	11.1
Pseudorasbora parva	23	20		9	86.9	39.1
*Micropterus salmoides**	72	49	12	8	68.0	11.1
Poecilia reticulata	49	38	7	8	77.6	16.3
*Salmo trutta trutta**	42	30	10	8	71.4	19.0
Lepomis gibbosus	31	23		8	74.2	25.8
Gambusia affinis	62	55	2	7	88.7	11.3
*Hypophthalmichthys molitrix**	74	36	30	6	48.7	8.1
*Lepomis macrochirus**	21	16	4	6	76.2	28.6
*Carassius auratus auratus**	63	54	2	5	85.7	7.9
*Clarias batrachus**	9	6	3	4	66.7	44.4
*Ctenopharyngodon idellus**	92	39	33	3	42.4	3.3
Poecilia latipinna	9	8		3	88.9	33.3
*Odontesthes bonariensis**	8	5	3	3	62.5	37.5
*Lates niloticus**	6	4	2	3	66.7	50.0

*Species used in commercial aquaculture.

Table 2. Top ten freshwater aquaculture species (2000).

Species	2000 Freshwater aquaculture production (mt)
*Hypophthalmichthys molitrix**	3,473,051
*Ctenopharyngodon idellus**	3,381,243
*Cyprinus carpio carpio**	2,718,277
Aristichthys nobilis	1,636,623
Carassius carassius	1,379,304
*Oreochromis niloticus niloticus**	904,848
Labeo rohita	795,128
Catla catla	653,440
Cirrhinus cirrhosus	573,294
Parabramis pekinensis	511,730

*Species with reported adverse ecological effects.

aquaculture, although contributing significantly, should be approached with care (FAO 1996).

Recommendations for action

Consolidation and common access through data sharing

Documenting the international movement of fish (artificial or otherwise) is one way of providing a general view of the magnitude of these movements and the existing and potential threat faced by these ecosystems. The information, however, is very limited and scattered in different journals and agency/project reports, and agency databases that provide information on the introduced and/or invasive species (terrestrial and aquatic, local, regional or international in scope). The critical challenge is for consolidation, common access through data sharing and development of risk assessment and management tools that take advantage of the diversity of available data and information.

It is proposed that there should be consolidation of information sources through the use of internet technology, sharing of databases or having a gateway or portal to which all introduced and invasive fish species related databases link. This would allow the information to be accessed more easily. In the interim and until Internet access becomes more widespread and relatively inexpensive, other media products, e.g. CD-ROMs and DVDs, should be produced and distributed.

The short species profiles and accounts provided by the different organizations (IUCN-GISD, NIS-USGS and FishBase-WorldFish Center, among others) on several of the more important invasive species are steps in the right direction. They provide information useful to researchers as well as decision-makers. The information include taxonomic classification, habitat, growth and reproduction. The information provided by the different websites have some commonality, some profiles are dynamic and interactive while others are static. However, the species lists are usually limited to species that are known to be invasive. Information on species that may be invasive in the future, if introduced to several countries and ecosystems, are usually

Table 3. Top ten freshwater aquaculture producers (2000).

Country	Freshwater aquaculture production (mt)				Introduced species production/total production (%)
	Status in country			Total (mt)	
	Native (mt)	Uncertain (mt)	Introduced (mt)		
China main	12,640,511	0	629,182	13,269,693	5
India	1,717,453	10,235	253,989	1,981,677	13
Bangladesh	278,000	0	226,000	504,000	45
Indonesia	63,903	31,629	243,329	338,861	72
USA	307,541	2,005	8,051	317,597	3
Thailand	69,082	71,276	119,270	259,628	46
Taiwan	60,082	0	58,922	119,004	50
Philippines	14,523	11,619	85,622	111,764	77
Brazil	12,379	0	82,465	94,844	87
Myanmar	93,948	0	0	93,948	0

not included. The fusion of these information sources would allow students, researchers, decision-makers and lawmakers to access updated and reliable information for present and future programs and projects.

The difficulty in accessing information on the impacts of the species may be the result of either the unavailability of references and/or the unavailability of information (no studies have been conducted). Both of these problems may be addressed by the consolidation of information sources. The first can be addressed by pooling the resources of different agencies and organizations with similar interests while the second can be addressed through the inclusion of identification of research gaps from the available resources that may lead to future studies. These solutions would benefit both developed and developing countries.

Development of risk assessment and management tools

Funding risk assessment research to obtain field data for each exotic species which has established self-reproducing populations in the wild is sometimes insufficient and, in developing countries, may be lacking. This problem though is extended to many developed countries whose governments are reluctant to invest in risk assessment research. Desk-top risk assessments are, therefore, usually done in lieu of field assessments. These are only as good as the data available to the assessor. Additionally, timeliness of the assessments is essential because of the urgency of some introductions.

Risk assessment methods have been largely based on expert opinion or are qualitative in nature (Kolar and Lodge 2002). It has also been widely perceived that predicting species invasions as well as which species are more likely to be invasive in the future is difficult, if not impossible (Enserink 1999) more so for introductions through ballast water. Deliberate and planned introductions should be subjected to risk assessment analyses prior to their introduction. Kolar and Lodge (2002) utilized information from databases such as FishBase for some biological and environmental variables in developing a quantitative risk assessment method to "identify alien species most likely to establish, spread quickly and become a nuisance". Information used from FishBase included human use, salinity tolerance, history of introduction, establishment or invasiveness elsewhere – at the genus and species levels. Kolar and Lodge were able to provide a quantitative, repeatable and transparent approach in risk assessment, characteristics, which have been identified by the US National Research Council as important to apply to future risk assessments.

Organizations and institutions can work together. Each will bring their individual and institutional strengths toward a computer-generated risk assessment tool drawing on information from various databases. This may not replace fieldwork and experimental trials, but the information could definitely provide an initial assessment and could be fine-tuned by researchers based on their own experiences and expertise. The values for this type of tool can be automated (automatically searching and inputting the values available in the databases), individually encoded or both (assessor can modify some default values to input others).

The proposed risk assessment tool will probably be a 3-step process.

1st – It will utilize the biological characteristics and ecological requirements of species (like growth rate, reproduction, food items, resilience, salinity and temperature ranges), combine percentage of establishment (from the existing database) and rank them.

2nd – Check areas/ecosystems where they have established as well as the species composition of the ecosystems.

3rd – Assess the area/ecosystem (bio-physico-chemical) where introduction of the species is planned to match it against the areas/ecosystems where the species has established.

This type of initial assessment could assist government agencies in their decision-making process regarding certain species (either by banning entry, quarantining the species for a given period or monitoring the species now found in the country). For some countries, however, this may be the only practical way to do risk assessment prior to the introduction of species. Eventually this may lead to government policies. However, insufficient data may lead to government actions or policies, which may not be scientifically sound. The more exhaustive and user friendly a risk assessment tool is, the better the chance that it would encourage researchers to use it.

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