COMMERCIALLY IMPORTANT CATADROMOUS FISH

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Summary

Anguillid eels is form by 15 species which are found in most areas of Indo Pacific regions, and in Atlantic ocean. They are amphihaline catdromous species which spawn in tropical deep seas and which migrate to inland brackish and freshwaters both in continental and insular water bodies where they spend several years growing. Their life history is characterized by two metamorphosis, first from leptocephali leaf like larvae to glass eels and then to growing “yellow eels”, and a second one from yellow to silver eels which are immature adults preparing their passage to the ocean. All anguillid are highly migratory species which migrate first from offshore spawning grounds to the inland growing areas, and second after several years back to the spawning grounds. The

biology, and especially the marine stages, are very badly known. Spawning areas have only been discovered in 3 species among the 15 listed ones. All eel populations from temperate regions (North and South Pacific, Atlantic) have been declining at least since the end of the 70's, fore badly known reasons. This is very worrying regarding the socio economic importance of the genus for many human societies that either fish them or farm them. However, since the breeding is not controlled, all the aquaculture depends upon the provision of lively seedlings, in general glass eels. Management and restoration plans have been developed in a number of regions, but they remain unsuccessful, probably because they are not conducted at the relevant level: the whole distributions are of each of the species. This implies that international, continental and intercontinental management plans need to be developed.

1. Generalities on the Anguillids

1.1 Systematics and Description

Eels are teleost (bony skeleton) fish belonging to Elopomorph Super Order, Anguilliform Order, and the Anguillid family. Anguilliforms are characterized by a long snake like body, without pelvic fins (apodes), and a very long fin formed by the junction of the dorsal, caudal and anal fins. The gill opening is narrow and the opercula bones are reduced in size. Maxillary teeth are present. The swim bladder is present and related to the esophagus by the pneumatophore duct. They all begin their life in marine and generally deep tropical waters. After hatching, the eggs produce leptocephali larvae that present a very different morphology from the adult stage. A very flat body looking like a willow leaf, with a very small head, characterizes them and in general the jaws present very long and pointed teeth indicating plankton based diet. After a time (several months to several years) spent as pelagic planktonic organisms, larvae measure in general less than 20 cm but leptocephali measuring over 50 cm have been reported in some species.
The Anguillid family is characterized by the presence of pectoral fins and small cycloid scales deeply incrusted in the derm. A single genus, "*Anguilla*," is reported, species being distinguished by their geographic distribution range and spawning areas, the relative length of anal and dorsal fins, and color (uniform, bicolor, and dots, etc) of sub adult stages. The disposition of maxillary and vomerian teeth, number of vertebrae and myomers are also used to identify species. A total of 15 to 19 species are reported according to authors, which accept or not the existence of *Anguilla ancestralis*, and whether some taxa are considered as subspecies or species. In general, it is now accepted that 15 species occur in Atlantic, Indian, and Pacific Oceans (see Table 1).

Species	Ocean
A. *anguilla*	Atlantic
A. *rostrata*	
A. mossambica	Indian
A. nebulosa	
A bicolor	Indo Pacific
A. megastoma	
A. australis	Pacific
A. borneensis	
A. celebesensis	

A. dieffenbachii	
A. interioris	
A. japonica	
A. marmorata	
A. obscura	
A. reinhardtii	

Table 1. List of anguillid eel species in the Atlantic, Indian, and Pacific oceans

1.2 General Biology and Ecology

1.2.1 Biological Cycle

It is generally admitted that eels are amphihaline migratory catadromous species, which means that, conversely to salmons, shads, sturgeons, and lampreys, the spawning takes place in marine offshore waters, whereas the growth occurs in continental coastal and/or inland waters. Therefore, all eel species have similar biological cycles (see Figure 1):

- Reproduction at sea in abyssal zones;
- Hatching produces leptocephali larvae;
- Long, and more or less passive migration to the continental shelf;
- Metamorphosis into glass eels and eels;
- Invasion of coastal and inland coastal environments and growth of yellow eels;
- Metamorphosis into silver eels;
- Downstream migration and marine migration towards spawning grounds.

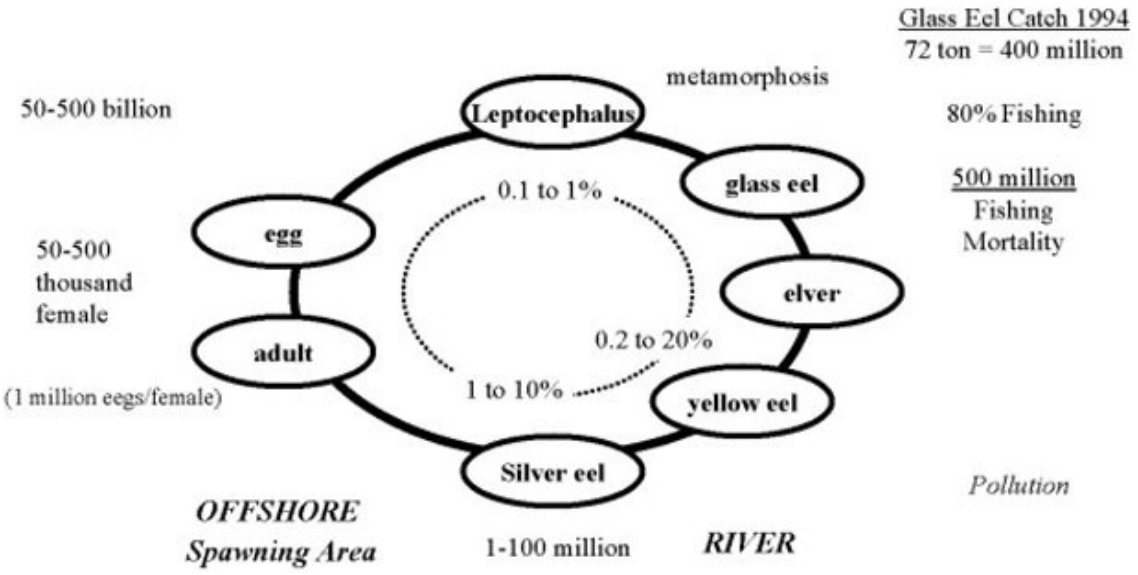

Figure 1. Shematic biological cycle of Eels (An example of population estimate of Japanese eel)

1.2.2 Reproduction

The reproduction of eels remains very poorly known, no observation of mating or eggs have been reported in the wild. Spawning has been obtained artificially in *A. anguilla* and in *A. japonica*. However, survival of larvae never succeeded, therefore, it is impossible to develop eel farming without collecting seedlings (mainly glass eels) from natural systems. The reproduction area is only known in 3 species: European (*A. anguilla*) American (*A. rostrata*), and Japanese (*A. japonica*). Some species, such as *A. marmorata*, probably have several spawning grounds. High hydrostatic pressures (> 40 atm, obtained at least at 400 m deep) together with warm temperatures trigger sexual maturation. It is generally accepted that breeders die after spawning following the long starvation period, which occurs during the transoceanic migration.

1.2.3 Leptocephali Stage

The morphology of the leptocephali indicates strong adaptation to pelagic marine environments. Marine currents such as the Atlantic Gulf Stream orient larvae migration towards continental or insular coasts. The duration of the migration is not well known and still discussed. It seems that: (i) leptocephali swim actively and therefore displacements are faster than the currents, and (ii) the duration of the transoceanic migration depends on the distance between spawning grounds and continental waters. However, the hypothesis of active drift across the Atlantic is much debated.

1.2.4 Glass Eel Stage

As they approach continental shelves, leptocephali stop eating, and metamorphose into glass eels. Many changes occur, anatomy (larval teeth fall, the section of the body becomes round), physiology (adaptation to freshwater) and behavior (preparation to inland invasion). Glass eels are considered as a transition stage between leptocephali and yellow eels. The upstream migration determinism of glass eels is relatively well documented in a number of species. According to species, it seems massive and concentrated on rather short periods (a few weeks) mainly in species of temperate areas (Northern and Southern hemisphere) whereas recruitment discreetly spreads all year long in tropical species. Marine currents, tidal currents, and river hydrology orient migration peaks. In tidal areas, migration is first passive, glass eels being transported by flood currents until they acquire an active migration behavior, which is characterized by an upstream orientation against currents. An unknown proportion of eels never invades freshwater systems and seems to stay in marine waters. As they colonize continental hydro systems, glass eels progressively acquire their sub-adult pigmentation.

1.2.5 Yellow Eel Stage

Elvers (smallest yellow eels of 0 age group), either colonizes inland brackish or freshwaters. Some stay in coastal environments or maybe even in marine offshore areas. The extent of inland waters colonized by eels depend on the species, some seem to stay in downstream reaches of rivers, whereas others invade whole river systems up to the source zones. Habitat range and suitability also varies according to species, biological stages (age) and sex. During this stage, eels are generally sedentary, although local migrations are observed either because of feeding behaviors or because of increasing densities, or according to age and size, or because of seasonal shifts of habitat

suitability. Depending on the abundance and the food availability, yellow eels may defend a territory or not.

Thus, yellow eels undergo a growth stage which duration depends upon the species, the sex and the geographic location of the growing habitat. During this period, eels have to store a sufficient quantity of fat to get prepared to the transoceanic migration and the breeding. Life strategy (sex ratio, fecundity, growth rate, and duration of the freshwater stage) can vary according to a latitudinal cline.

1.2.6 The Silver Eel Stage

Silver eel stage has not been reported in all species, i.e. *A. marmorata*. In other species, yellow eels undergo a metamorphosis once they have reached minimum size and weight that are specific to each sex and can be highly variable. There is a strong sexual dimorphism, females always being much bigger and able to become older than males whatever the species. Many changes occur, and concern a preparation to marine environments. The eyes' volume increases and retinian pigments are modified, pectoral fins grow longer, the skin thickens, the yellow pigments disappear and therefore, the back becomes darker whereas the belly is white. The gonads start developing, but the final maturation will only be achieved in marine waters. Once the metamorphosis engaged, silver eels start their downstream migration towards marine waters. The digestive tract then regresses indicating starvation, which is thought to last until spawning. This suggests that fat stored during the growth has to provide for swimming energy and sexual maturation. The marine migration is not known, radio tracking being difficult because of the depths at which eels migrate. The only reported experiments permitted to track European silver eels at about 100 km from the coast. A few gravid females have been photographed at important depths in the Atlantic.

1.3 Ecology

1.3.1 Distribution

Except in the eastern Pacific Ocean and the Southeast Atlantic Ocean, eels are present in all temperate and tropical waters. In inland water systems, eels are quite ubiquitous. They are found in practically every kind of habitat, from the sources to the estuary and coastal environments. They can be the only species, which occurs in unsuitable environments for other fish species, mainly shallow waters. Stocks and densities vary mainly according to two factors: (i) densities decrease regionally with the distance from the spawning grounds, and (ii) within a catchment, the abundance decreases with the distance from the sea more or less rapidly according to species, biological stage and presence of natural or man made obstruction.

1.3.2 Diet

Eels are carnivorous consumers. Nevertheless, diet changes with age and stages. The food of leptocephali larvae is not very well known and is subject of controversies. According to authors, they are thought to feed on living preys, on detritic organic matter, or even on dissolved organic matter. However, the structure of the dentition is

characteristic of zooplankton feeders, which is the diet reported for most fish larvae. Glass eels start eating after the pigmentation appears and generally small benthic food items are grazed such as chironomid and other insect larvae, worms, etc.

Sub adult eels are considered omnivore: they generally consume zoobenthic preys but fish, organic detritus, and plants are also present in the stomach content. These fish appear to be highly opportunistic which involves very variable diets according to the size and the availability of preys in the environment.

Young elvers and small individuals focus on living or dead meiofauna and small invertebrates, the size of selected preys increasing as the eels grow. Most often, large eels acquire piscivorous diets. Cannibalism has been observed, mainly on elvers, and small eels.

1.3.3 Role in Aquatic Biocenose

European and American leptocephali larvae account for an important proportion of animal biomass in the Sargasso Sea. It is probably the same for other species of eels on their spawning areas..

In most continental waters eels are an important component of fish communities and they represent essential food items for many predators such as ardeids or otters. A decline of these populations' strength could therefore disturb the balances of the aquatic biocenoses, and even the functioning of hydro systems, considering the role migratory species often play in organic matter fluxes between marine and continental waters.

1.4 Evolution

The marine character of anguilliforms suggests that anguillids were originally marine species, which acquired secondarily an amphihaline behavior. All the anguillids spawn in tropical regions and only 5 species are found in temperate continental waters. More than 2/3 of the species occur in west Pacific regions, suggesting that the actual species derive from an ancestral eel. Some authors suggest that *A. celebensis* occurring in the Borneo-Sumatra regions could be the common ancestor of all the modern species.

Speciation in *Anguilla* genus is thought to have originated by the continental drifts and the linked paleogeography. Ancestral eels, present in the Tethys, Sea were probably drifted westerly by a global circum equatorial current. As a matter of fact, the oldest *Anguilloid* known fossils are 100 million years old (Cenozoic). They were found in the sediments of the Mesogean Sea in Lebanon and Southern France. This sea formally connected Atlantic and Thethys (Pacific) Oceans. Progressively, its surface diminished and finally formed the Mediterranean Sea. Pacific and Atlantic became separate.

Ancestral eels, present in the Tethys Sea were probably drifted westerly by a global circum-equatorial current, and split into two groups: the present Atlantic eels and the African/Australian eels. Most speciation among the lineages is thought to have occurred during Eocene and Oligocene, 45–50 million years ago, although the two Atlantic species separated about 10 million years ago.

2. Atlantic Eels

2.1 Distribution and Stocks

Both Atlantic eels spawn in the Sargasso Sea, American eels in the western part where as European eels are thought to have more easterly spawning grounds. Continental (coastal and inland) stages are mainly distributed in the temperate zone of the Northern hemisphere, despite some are found down to the Cancer Tropic (see Figure 2). Actually no eels are reported in Southeast South America and in Southwest Africa.

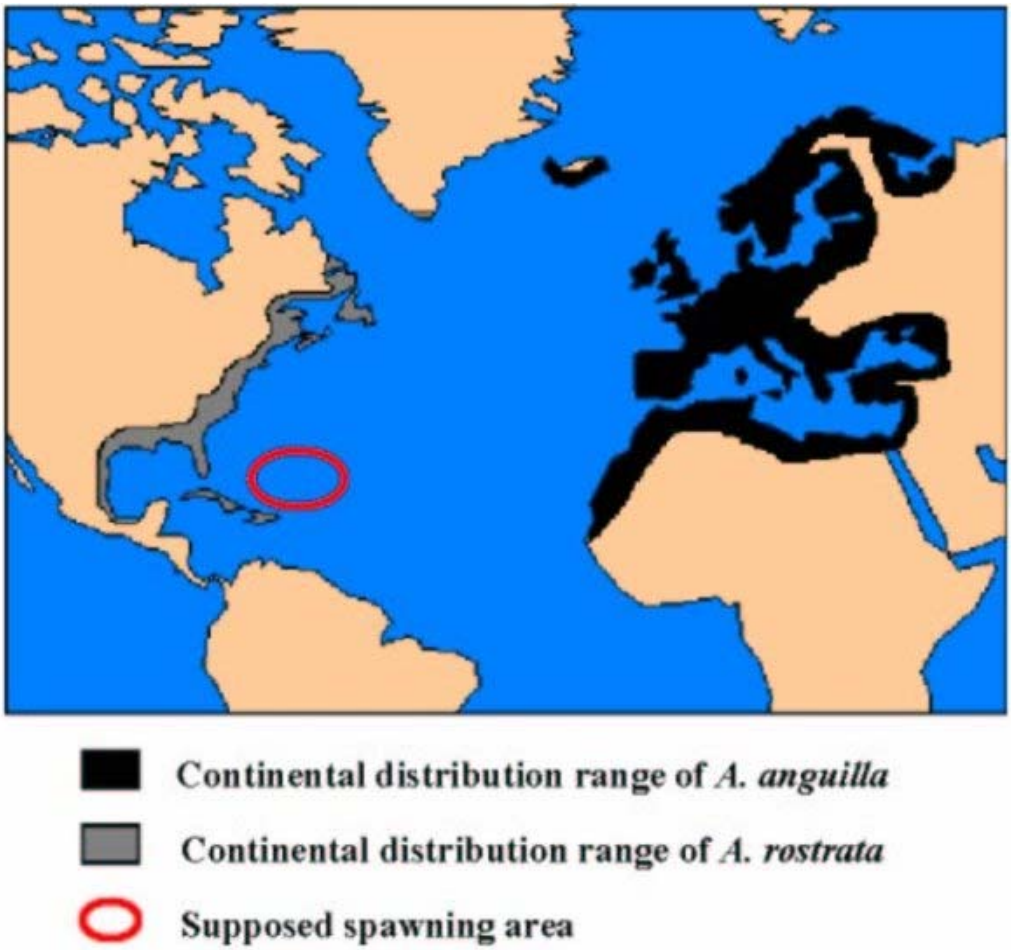

Figure 2. Distribution range of Atlantic eel

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Biographical Sketches

Eric Feunteun graduated from Rennes University, France with his Ph.D. Natural Science. He is now appointed as an Associate Professor of the University of Rennes. His research topics focus both on coastal saltmarsh estuarine ecological functioning, and in freshwater eel biology. He developed research on eel dynamics in inland waters, to study relations between recruitment variation (immigration of young eels), population characteristics (size, density, age structure, mortality, growth etc) and downstream migration of silver eels. He also develops models to explain and predict such variations of population characteristics at the scale of whole river systems. His implication in eel research led him to become the chairman of the French research group on eel acknowledged by the Ministry of Environment. Eric Feunteun is involved in EIFAC ICES European working groups on eels. He also develops research on tropical eel species occurring in the indo pacific regions, mainly in insular systems as New Caledonia, Tahiti archipelago and Mascareigne region. He is member of several scientific societies.

Pascal Laffaille is a post doctoral fellow now working at the University of Toulouse. He passed his PhD at University of Rennes where he worked on interactions between fish communities and tidal saltmarsh estuarine systems of the Bay of Mont Saint Michel (France). Pascal Laffaille also worked on European eel communities, especially to estimate the role eels in organic matter transfer between continental and marine environments. He now works at developing artificial neuronal network models to estimate and predict distribution of fish community from population and habitat characteristics.

Jun Aoyama is a post doctoral fellow who graduated from the University of Tokyo and is presently working at the Ocean Research Institute in Tokyo. He works on the ecology of freshwater eels with a focus on the evolution of their catadromous migrations using both molecular genetic and behavioral research techniques. Jun Aoyama is involved in studies conducted not only in Japan, but also in Indonesia (with the Sam Raturangi University, Sulawesi Island), and in Iceland (with the Freshwater Fisheries Center, Holar).

Marie Noelle de Casamajor is a post doctoral person. She passed her PhD doctorate in the University of Pau (southern France) for the French marine research institute (IFREMER). Her research focused on the mechanisms underlying estuarine recruitment of European glass eels. She is now working in the same institute, to continue her work on recruitment with a special focus on seasonal variations of life history, behaviour and physiological characteristics of glass eels.

Pierre Dumont is a fisheries biologist, working in Québec freshwater ecosystems since the beginning of the 1970s, when got involved in the impact studies of the James Bay hydropower development. He works for the Québec government since 1978, first as a regional biologist in the Outaouais region and, since 1982, in the St. Lawrence River lowlands, in the most urbanized part of the province. He is mainly involved in scientific studies on the status and the exploitation of lake sturgeon, yellow perch and american eel, on the long term monitoring of fish communities along the St. Lawrence River, on fish habitat improvement and on the restoration of the cooper redhorse, a rare and endangered species, endemic to southwestern Québec. He is also involved in the restoration of the European sturgeon, for which he made a one year stage in France in 1998-1999. He received his doctoral degree in Environmental sciences from the Université du Québec à Montréal in 1996.

Don Jellyman completed his PhD on the ecology of juvenile New Zealand freshwater eels in 1973. Since then, he has continued to carry out research on the biology of freshwater fishes and the implications of environmental changes on freshwater fish stocks. He has published widely on the recruitment, migrations, and growth of New Zealand eels and attended EIFAC ICES European working groups on eels. He is presently employed as a freshwater fisheries biologist by the National Institute of Water and Atmospheric Research.