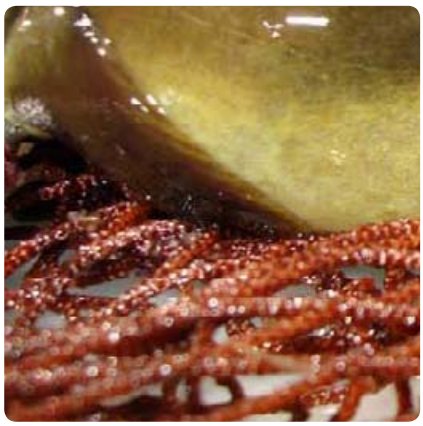
NATUR VÅRDS VERKET

CITES Identification Guide to the Freshwater eels (Anguillidae)

with Focus on the European eel *Anguilla anguilla*

REPORT 5943 • MARCH 2009



CITES Identification Guide to the Freshwater eels (Anguillidae)

with Focus on the European eel *Anguilla anguilla*

by Dr. Anders M.C. Silfvergrip
Swedish Museum of Natural History
Stockholm, Sweden

Contact: anders.silfvergrip@nrm.se

Version 1.1

SWEDISH ENVIRONMENTAL
PROTECTION AGENCY

Order
Phone: + 46 (0)8-505 933 40
Fax: + 46 (0)8-505 933 99
E-mail: natur@cm.se
Address: CM gruppen AB, Box 110 93, SE-161 11 Bromma, Sweden
Internet: www.naturvardsverket.se/bokhandeln

The Swedish Environmental Protection Agency
Phone: + 46 (0)8-698 10 00, Fax: + 46 (0)8-20 29 25
E-mail: registrator@naturvardsverket.se
Address: Naturvårdsverket, SE-106 48 Stockholm, Sweden
Internet: www.naturvardsverket.se

ISBN 978-91-620-5943-9
ISSN 0282-7298

Print: CM Gruppen AB
Cover photos: *Anguilla anguilla* by Anders Asp, Swedish Board of Fisheries

Preface

At the 14th meeting of the CITES Conference of the Parties in The Hague (Netherlands, 3–15 June 2007) it was decided that the European eel *Anguilla anguilla* would be listed in Appendix II. The listing means that all international trade is subject to strict regulation in order to avoid utilization incompatible with the species survival.

Sweden, as the author of the proposal for the listing, has produced this identification guide as an aid for the enforcement of the regulation. In addition, education material is in preparation and a brief fact sheet has been published. The latter is intended to be used by Customs officers at an initial control.

The designation of geographical entities in this publication, and the presentation of the material, do not imply the expression of any opinion whatsoever on the part of the Swedish Environmental Protection Agency concerning the legal status of any country, territory, or area, or of its authorities, or concerning the delimitation of its frontiers or boundaries.

Opinions expressed in this report are those of the author and do not necessarily reflect the official view of the Swedish Environmental Protection Agency.

Stockholm, March 2009

Swedish Environmental Protection Agency

Contents

Abstract

The recruitment of the European eel *Anguilla anguilla* has declined drastically during the last decades. One reason is that the species is widely traded and the European eel is therefore listed in Appendix II of CITES. It is also listed as Critically Endangered in the IUCN Red List. This identification guide aids the enforcement of the CITES listing by providing those in need to identify the European eel with the necessary protocols and background information.

The guide describes suggested protocols for Customs officers, such as sampling procedures and choice of accredited institutions for species identification. Institutions shall have documented capacity for morphological and molecular identification as well as long term storage of tissue samples. The guide also details the protocols for both morphological and molecular identification.

The guide includes diagnostic descriptions of the internationally most traded eel-shaped fish families and new diagnoses and a morphology-based key to all 15 eel species of the family Anguillidae, genus *Anguilla*. Because of intraspecific variation, morphological identification is always recommended to be coupled with molecular identification. It is recommended using a newly developed primer pair for *Anguilla anguilla* which also allows identification of processed eels, e.g. smoked eel. Mixed species shipments can only be detected with certainty using molecular methods.

Sammanfattning

Återväxten av europeisk ål *Anguilla anguilla* har minskat drastiskt de senaste decennierna. En orsak är den omfattande handel som bedrivs med arten. Europeisk ål har därför tagits upp på bilaga II till CITES-konventionen. Den är också upptagen som Akut Hotad (”Critically Endangered”) i IUCN:s rödlista. Den här vägledningen för identifiering av ål bistår verkställandet av CITES-konventionens listning. De som är i behov av artbestämning av europeisk ål får här de nödvändiga verktygen samt en hel del bakgrundsinformation.

Vägledningen beskriver de rekommenderade rutinerna för tulltjänstemän, som stickprovsförfarande och anlitande av ackrediterad institution för artbestämning. Institutionen bör ha en dokumenterad kapacitet för både morfologisk och molekylär artbestämning samt långsiktig förvaring av vävnadsprover. Dokumentet beskriver också i detalj förfaranden för både morfologisk och molekylär artbestämning.

Vägledningen beskriver vidare särskiljande kännetecken för de vanligast förekommande ålformade fiskfamiljerna inom internationell handel samt har nya artdiagnoser och en morfologibaserad bestämningsnyckel till samtliga 15 ålarter inom familjen Anguillidae, släktet *Anguilla*. På grund av inomartsvariation rekommenderas alltid även molekylär artbestämning. Det rekommenderas att nyutvecklade primrar används, vilka beskrivs i detalj, som dessutom tillåter artbestämning av behandlad ål, t.ex. rökt ål och andra produkter. Försändelser med flera arter kan enbart upptäckas med säkerhet med hjälp av molekylära metoder.

Suggested protocol for Customs

If transported goods can be suspected to be or can be positively identified as freshwater eels, either through documentation or random visual inspection, Customs officers shall perform the steps described below.

The shipment shall proceed without delay after sampling has been done.

- Take note of all documentation, including stated species (one or several), shipment size, number of boxes, stated origin(s), exporter, importer, final destination, etc
- Take photographs of the entire shipment and at least one individual shipment box. In the case of live specimens, take photographs of container(s) and if possible, live specimens in side view; many times a registered expert may determine if further steps are necessary.
- Customs samples from glass eel shipments should be at least 15 specimens from at least two separate shipment boxes. Send the specimens (at least 2×15) alive to accredited institution for morphological and molecular identification. Keep each sample well separated *and* marked with box number. Keep each sample of at least 15 specimens well separated and marked with box number.
- Customs sample from shipments with live adult specimens should be at least 15 specimens. Send these transported live to accredited institution for morphological *and* molecular identification.
- In case of live specimens, tissue sampling shall be done at the accredited institution, by personnel trained in euthanasia.
- Processed eel (smoked, grilled, canned, etc.) may be sent directly to the accredited institution. Coordinated efforts with National Food Administrations may prove beneficial.
- All Customs samples should be sent to the accredited institution together with this guide, unless they already have it.
- Customs officers should take note of the accredited institution's registration number for the Customs sample. This is important for later traceability of specimens and tissue samples as well as supplementary interlaboratory analyses.
- Results and complete protocols from accredited institution should normally be available within one week.

It is recommended that Customs use accredited institutions for identification of eel species. Designation of accredited identification experts and/or institutions should in particular consider their ability to perform (1) fish identifications using morphology, (2) fish identifications using molecular analysis and (3) long term storage of specimens and tissue samples for later revalidation of identifications; see also Conf. 11.15, Rev. CoP12 (/www.cites.org/eng/res/all/11/E11-15R12.pdf) for certification of institutions for additional relevant criteria.

Suggested protocol for accredited institution

Upon receipt of the Customs sample the accredited institution shall perform the following steps:

- Take note of all documentation, including stated species (one or several), shipment size, number of boxes, stated origin(s), exporter, importer, final destination, etc. Information will be received from Customs officers.
- Take photographs of the entire sample at reception. In the case of live specimens, take photographs of container(s) and if possible, a live specimen in side view.
- In case of glass eels and eels smaller than 200 mm total length, perform species identification of each individual of the at least 2×15 specimens using morphological, and, a molecular identification. Keep each sample of at least 15 specimens well separated and marked with shipment box number and unique register number later used in both morphological and molecular analyses.
- In case of eels larger than 200 mm TL, perform species identification of each individual of the at least 15 specimens using morphological and, if deemed necessary, a molecular identification. Keep each 15 specimen well separated and individual marked with shipment box number and a unique register number later used in both morphological and molecular analyses.
- In case of processed eels, perform species identification of each sample.
- Customs sample from shipments with live specimens shall be euthanized according to best practice not interfering with subsequent identification using either morphological or molecular methods.
- For live or intact eels, morphological identification shall consider all three keys listed under “Morphological identification” in order.
- If morphological identification is not possible, a brief explanation detailing why identification failed shall be given on an individual, per specimen basis. All necessary details on a per specimen basis surrounding positive morphological identifications shall be included in the report to Customs.
- Molecular identification may use any of the suggested protocols listed under “Molecular analyses”. The same protocol shall be applied on all specimens. All necessary details for repeated analysis surrounding the molecular analyses shall be included in the report to Customs.
- Perform a preliminary identification versus the BLAST database at GenBank and BOLD databases at CBOL. The result shall be included in the report to Customs.

- If deemed necessary, accredited institution may perform a full phylogenetic analysis using any of the three algorithms (Maximum-Parsimony, Maximum-Likelihood, and Bayesian analysis). All necessary details on a per specimens basis surrounding a phylogenetic analysis shall be included in the report to Customs.
- Results of the morphological and molecular analyses shall be reported to Customs as soon as possible. The report shall contain all necessary details on a per specimen basis.
- Accredited institution shall provide space for long-term storage of intact specimens, all tissue samples, and all amplified PCR products for as long as relevant authority deems necessary.
- Accredited institution may after relevant authority's decision choose to retain or dispose the samples.
- Protocols for morphological and molecular identifications may be updated on short notice and Customs will provide the latest regulatory methods.
- Note that morphological identification requires a low-voltage x-ray equipment for examining vertebral numbers.
- Primers and the necessary laboratory equipment shall always be available for molecular identification.

Report from accredited institution, example

Box	Shipment id	Customs number	Stated origin	Stated destination
23	#2009-0893876	#9847-7894	Somewhere	Elsewhere

Spm	Catalog number	Morphology	Molecular method	Species identification
1	AAA W-974987	key	CO-I + Cytb-AngF/R BLAST	*Anguilla anguilla*
2	AAA W-974987	key	CO-I + Cytb-AngF/R BLAST	*Anguilla anguilla*
3	AAA W-974987	key	CO-I + Cytb-AngF/R BLAST	*Anguilla anguilla*
4	AAA W-974987	key	CO-I + Cytb-AngF/R BLAST	*Anguilla anguilla*
5	AAA W-974987	key	CO-I + Cytb-AngF/R BLAST	*Anguilla anguilla*
6	AAA W-974987	Visual inspection	Not applicable	NOT *Anguilla anguilla*
7	AAA W-974987	key	CO-I + Cytb-AngF/R BLAST	*Anguilla anguilla*
8	AAA W-974987	key	CO-I + Cytb-AngF/R BLAST	*Anguilla anguilla*
9	AAA W-974987	key	CO-I + Cytb-AngF/R BLAST	*Anguilla anguilla*
10	AAA W-974987	key	CO-I + Cytb-AngF/R BLAST	*Anguilla anguilla*
11	AAA W-974987	key	–	*Anguilla anguilla*
12	AAA W-974987	key	CO-I + Cytb-AngF/R BLAST	*Anguilla anguilla*
13	AAA W-974987	key	CO-I + Cytb-AngF/R BLAST	*Anguilla anguilla*
14	AAA W-974987	key	CO-I + Cytb-AngF/R BLAST	*Anguilla anguilla*
15	AAA W-974987	key	CO-I + Cytb-AngF/R BLAST	*Anguilla anguilla*

Remarks: All specimens between 80 and 90 mm in total length, slightly pigmented. Specimen No 6 is NOT an *Anguilla anguilla*, as determined by visual inspection; possibly not even an eel. Specimen No 11 does not amplify but agree with other specimens in morphological analysis. PCR protocol as per Silfvergrip (2009) All specimens individually tagged and stored in deep freezers in basement for reference. (Report continued on separate form).

Introduction

The recruitment of the European eel *Anguilla anguilla* has declined drastically during the last decades. One reason is that the species is widely traded. The European eel is therefore listed in Appendix II of the Convention on International Trade In Endangered Species of wild fauna and flora (CITES 2006, 2007, 2008). This regulation came into force on 13 March 2009. Since 2008, the European eel is also listed on the IUCN Red List as Critically Endangered (Freyhof and Kottelat 2008). The objective of the identification guide is to aid the enforcement of the listing by serving those in need to be able to identify the European eel. It also covers all other, non-European eel species and may therefore be used by a larger audience. The document summarizes the recent advances in eel studies with a focus on the identification of the European eel, and reanalyses previously published data while providing new results.

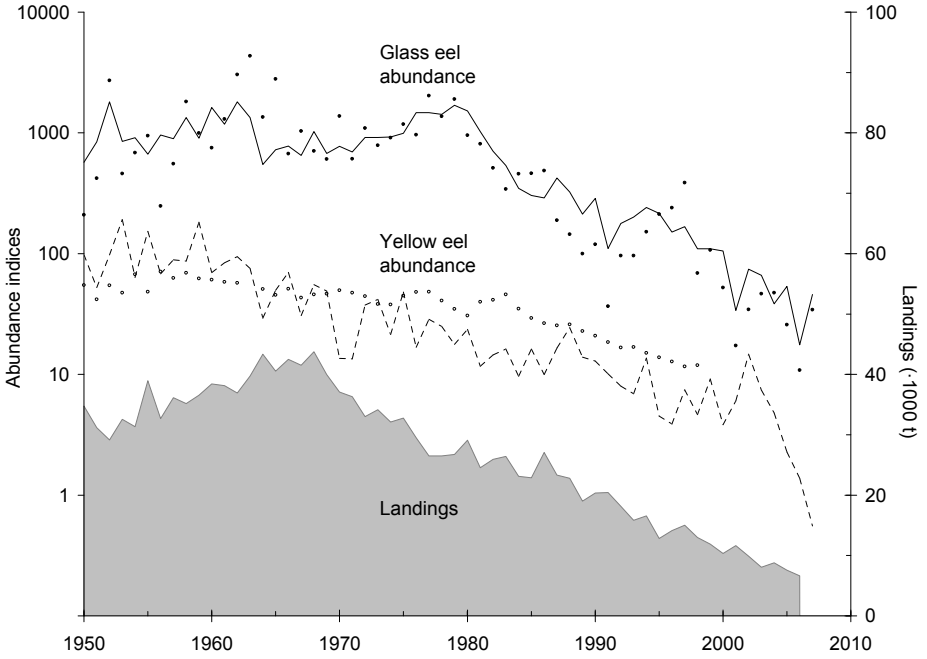


Figure 4. Trends in abundance and landings of the European eel (*Anguilla anguilla*). Data from Dekker (2004) with updates kindly provided by Dr. Willem Dekker (19 Dec 2008). Compare with Table 5 for other species of Anguillidae.

The guide is arranged to aid in visual inspection, morphological identification, and molecular identification. Often visual inspection is the initial step and may obviate the need for subsequent detailed morphological and molecular analyses. The morphological identification keys are constructed so that all species characteristics must be considered for the positive identification of the European eel. For processed eels, molecular analysis is required. While the

focus has been the positive identification of the European eel, positive identification of other eel species increases the certainty that we do not have the European eel at hand. Positive identifications of fish samples have in recent years become reliable, even when the morphology or the origin of the sample is unknown (Sevilla *et al*. 2007, Yancy *et al*. 2007, Deeds *et al*. 2007, Costa and Carvalho 2007, Rock *et al*. 2008, Rasmussen and Morrissey 2008, Wong and Hanner 2008, Hubert *et al*. 2008).

There are a number of non-exclusive factors suggested to explain the decline in recruitment of the young of the eel, known as glass eels, which include over-fishing, pollution, migration blocks, habitat loss, parasites, and changes in sea temperature and sea currents. Dekker *et al.* (2007) summarized that none of the suspected factors may alone explain the decline. It has been recognized that also the American eel (*Anguilla rostrata*) and Japanese eel (*A. japonica*) have seen a similar decline for about the same time period and then possibly influenced by the same or similar factors.

In the remainder of this document the term "adults" is intended to mean yellow and silver eels.

Morphological identification

The identification part is organized in three sections: key to similar families, key to the glass eels, and key to the adults. The key to similar families should always be the first consideration, whereas the other two depend on the size of the specimens.

The meristic and morphometric data mainly come from Ege (1939) with additional data from Jespersen (1942), Aoyama *et al*. (2000), Watanabe *et al*. (2006), and Minegishi *et al*. (2008). Unfortunately, Ege's raw data have never been located (P Rask Möller and J Nielsen, pers. comm.) and many statistical analyses have therefore not been possible to perform as they require data sets in a matrix shape and cannot be recreated to its original form. Data presented here have been extracted from Ege's tables and backcalculated for a reduced set of statistics.

There are some technical requirements for identification of freshwater eels of unknown origin. Morphological identification of glass eels requires a binocular stereoscope ("stereomicroscope") and a sharp-jawed vernier caliper graded to 0.1 mm. Specimens larger than 200 mm total length also requires a low-voltage radiograph equipment. The single radiograph shown in Figure 2 (B-D show details) was taken at the Swedish Museum of Natural History with a Philips MCN-101 at 25kV and 750 mAs, with the radiograph plate scanned using a Hewlett-Packard ScanJet G4050 with a backlit lid. The radiograph image was scanned twice at 600 dpi and combined to about 7,500 pixels width (reduced to 2,000 pixels for Fig. 2 A and 500 pixels for Fig. 2 B-D). Regular Customs x-ray machines used at airports (e.g. Smiths Heimann Hi-Scan 6040i and 6046si) have been tested, but were not able to produce radiograph images of sufficient detail to be used in this context (see Figure 1).

There is no comprehensive information available for the identification and comparison of eel eggs using morphology (Castle 1984) but it is known that the eggs of anguilliforms in general resemble large clupeid eggs, e.g. those of herring (McGowan and Berry 1984). Identification of anguillid eggs and leptocephalus larva require molecular analysis (Aoyama *et al*. 2007).

While there are reports on species mixed in commercial trade (Lin *et al*. 2002) it is difficult to determine the presence of two species in glass eel shipment using small samples and morphology. Therefore, supplementary molecular analyses are necessary.

Sample size

There is great intraspecific variation and the ranges of many characters often show considerable overlap between species (Watanabe *et al*. 2004a). This was realized by Ege (1939) who used both means and standard deviations in order to describe his material.

Data have been extracted from tables in Ege (1939) and other sources. Statistics have been recalculated, which now include the mean, the median, and the 99% bootstrap (median) confidence intervals (Efron and Tibshirani 1986). All calculations were done using the statistical package R (version 2.7.2, www.r-project.org/) and adapted implementations of Efron and Tibshirani's models as modified by Charles Geyer, University of Minnesota (www.stat.umn.edu/~charlie/).

The intervals for the ratios between the tail lengths and the anodorsal distances for *A. anguilla* and *A. japonica* were determined in several steps: a bootstrap regression on log-log data with 10,000 replicates for each species, were the resulting equations with standard deviations for each data set were used to generate samples with 10,000 records, which lastly were used to estimate the 99% bootstrap (median) confidence intervals.

The sample size 15 was empirically determined to produce intervals usable in the identification keys and diagnoses. Deviations from the suggested intervals may have several causes, including that of mixed species samples. There is a trade-off in the benefit of mixing two species between discovery and economic gain. Therefore 15 specimens should be on the safe side, with a strong deterrent effect, in particular with concomitant molecular analyses. It may be noted that the sample mean is more sensitive to detect mixed species samples than the robust sample median.

Body proportions have been expressed in per cent of other body parts, and referred to as, e.g. % of TL (per cent of total length), % of HL (per cent of head length, etc.). Body proportions which show growth allometry have been compensated for in keys. The total length (TL) is measured in a straight line from the tip of the lower jaw to the end of the tail. The head length of freshwater eels is measured from the tip of the lower jaw to the gill opening, as a point to point distance (Ege 1939).

Mouth

The lower jaw is invariably protruding beyond the upper jaw. The lower jaw lips are well developed but often slighly thinner than the upper jaw lips. The lips meet at the mouth angle. All data on mouth size comes from Ege (1939) who measured: "the distance from the tip of the lower jaw to the corner of the mouth itself, the lips round this being left out of consideration" and "measured in a straight line from the tip of the lower jaw to the angle of the gape" (Ege 1939, p. 17). During maturation the mouth stops growing whereas other parts in the head region continue to grow. The result is that the mouth becomes proportionally smaller at a maturation. Among the freshwater eels there are two size classes of the gape size (Table 12), species with a larger mouth (sample median above 31% of HL) and those with a smaller (sample median below 28% of HL). The 99% confidence intervals are based on 10,000 bootstrap replicates with a sample size of 15.

Tooth bands

Ege (1939) examined and illustrated a large number of tooth bands in anguillids and his taxonomy is in large parts based on that character. Tooth-bands are difficult to examine and may in some cases be overlapping in shape between species (Aoyama *et* al. 2001) and they have therefore been given a later position in the keys, compared to Ege's key. Tooth bands are not included in the key to glass eels as they are not sufficiently well developed for identification.

A

B

C

Figure 1. Radiograph of *Anguilla* spp (550–600 mm TL) using regular Customs high-voltage radio-graph ("x-ray") equipment (140kV, 300mAs). A. Radiograph using Smith-Heimann Hi-Scan 6040i. B. Radiograph using Smith-Heimann Hi-Scan 6046si. C. Radiograph using Smith-Heimann Hi-Scan 6046si, detail of head region.

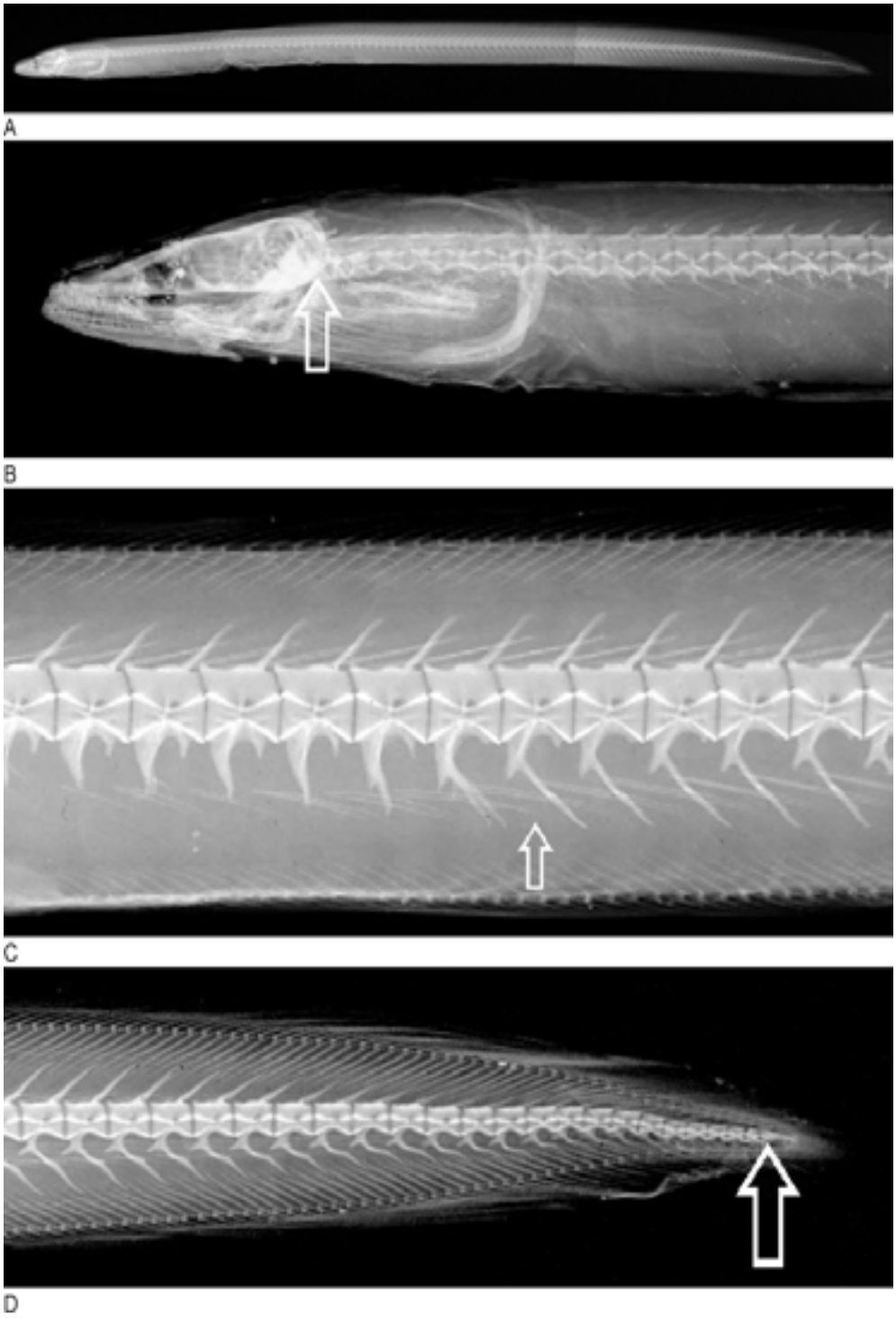


Figure 2. Radiograph of *Anguilla anguilla* (NRM 31610, 296 mm TL) using low-voltage radiograph equipment (25kV, 900mAs). A. lateral view. B detail of head region; arrow at first prehaemal vertebra. C. detail of midbody; arrow at first caudal vertebra. D. detail of tail region; arrow at last caudal vertebra.

Coloration

There are two main colour patterns in freshwater eels, plain and marbled; see illustrations in "Key to glass eels and young freshwater eels" below. The marbled colour pattern is interchangably also known as variegated or mottled and most easily seen in the adults. It is not present in glass eels or the youngest life stages. Both plain and marbled colour exhibit great variation in colour tones, shades and intensity which, however, may be useful for identification of eels at a local level. Post-mortem discoloration may produce an irregular, blotchy pattern which should not be confused with the regular, variegated color pattern.

Vertebrae

Tables 9-11 present the frequency distribution of vertebral counts based on data from Ege (1939), Jespersen (1942), Aoyama *et al.* (2000), Watanabe *et al.* (2006), and Minegishi *et al.* (2008). The tables also list the median, mean and the 99% confidence intervals based on 10,000 bootstrap replicates with a sample size of 15. The first vertebra, is located at the skull posterior base, about 8 vertebrae in advance of the gill-cover posterior margin (see arrow in Figure 2 B). The last vertebra was defined by Ege (1939) as "all behind the last hour-glass shaped vertebra being taken as one vertebra". The first caudal vertebra (or prehaemal vertebra) has a closed haemal arch which may be difficult to detect in lateral view (see arrow in Fig 2 C); Ege (1939) recommended dissection if necessary. For increased visibility of vertebrae one may use staining techniques, e.g. Alcian blue for cartilage and Alizarin red for bone (Taylor & Van Dyke 1985).

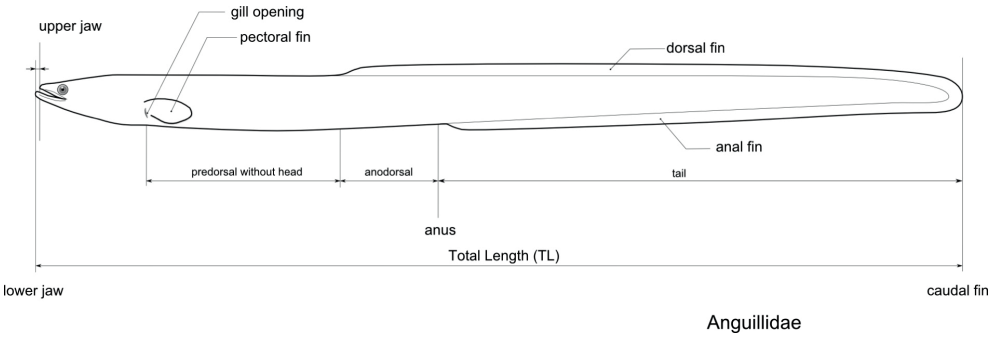


Figure 3. Schematic drawing of an anguillid indicating characters used for identi cation.

(1) Key to similar families

There are more than 30,000 known fish species (FishBase, www.fishbase.se) and there may well be more than a thousand fish species with an eel shape. The typical eel shape is common among burrowing and bottom-living ("demersal") animals and is therefore also present in numerous fish groups not related to the Anguilliformes. The high number of eel shaped fish has practical consequences for anyone unfamiliar identifying fish using morphology.

Freshwater eels (Anguillidae, *Anguilla* spp.) can be recognized from all other eel-shaped fish commonly found in the trade by a unique set of characters. Eyes well developed. Posterior nostril in front of eye. Jaws well developed, with the lower jaw invariably the longer. All fins without hard spines. One dorsal fin, long, low, and remote from head. Anal fin long, low, to just behind anus. Caudal fin confluent with both dorsal and anal fins. Pectoral fins well developed. Pelvic fins invariably absent. Barbels invariably absent (not to be confused with short tubular nostrils). Anus located just in advance of mid-body. Gill openings paired, well separated left and right side openings as small vertical slits at pectoral fin base. Scales invariably present, but often hard to detect.

Here, it is focussed on contrasting the freshwater eels to 13 other fish families with eel-shaped representatives known to occur in significant numbers in the global production of fish (Table 6), using statistics from FAO – Fisheries and Aquaculture Information and Statistics Service (www.fao.org). It is not arranged as a traditional identification key, as many of the diagnostics features commonly are removed in the trade before presented to the customers, e.g. venomous spines in catfish. Decapitated anguilliforms are very hard to distinguish from each other and molecular analysis may be the only option for identification.

Order Myxiniformes / Family Myxinidae – Hagfishes

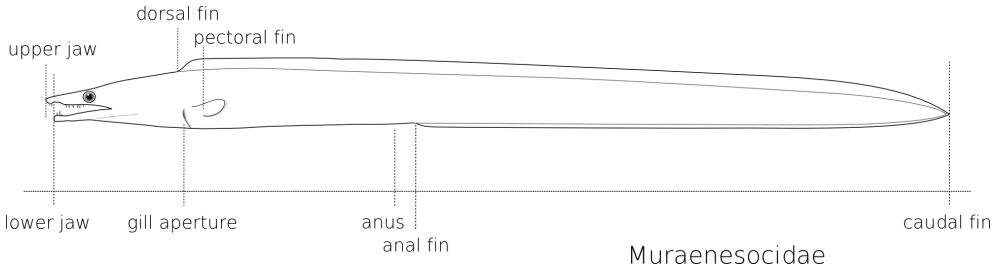
The hagfish are a small group of eel-shaped fish found in deeper waters throughout the world. The skin of hagfish, as well as freshwater eels, are typically used for fish leather, and sold as "eel skin" (Grey *et al*. 2006). Hagfish are readily distinguished from freshwater eel by (1) lack of long, well developed jaws (distinct in freshwater eels); (2) eyes degenerate, hardly visible (well developed and distinct in all freshwater eels); (3) completely lacking pectoral and pelvic fins (pectoral fins well developed and pelvic fins absent in freshwater eels); (5) caudal fin distinct or confluent with anal fins (always confluent with dorsal and anal fins in freshwater eels).

Order Petromyzontiformes / Family Petromyzontidae – Lampreys

The lampreys are a small group of eel-shaped fish found in both fresh waters and marine habitats seas in temperate seas. Lampreys are used as food for humans in many parts of the world Lampreys are distinguished from freshwater eel by (1) a conspicuous series of seven gill openings behind the eye; (2) completely lacking pectoral and pelvic fins (pectoral fins well developed and pelvic fins absent in freshwater eels); (3) lack of well developed jaws but rather a sucking disc with concentric series of small teeth (jaws well developed and distinct in all freshwater eels).

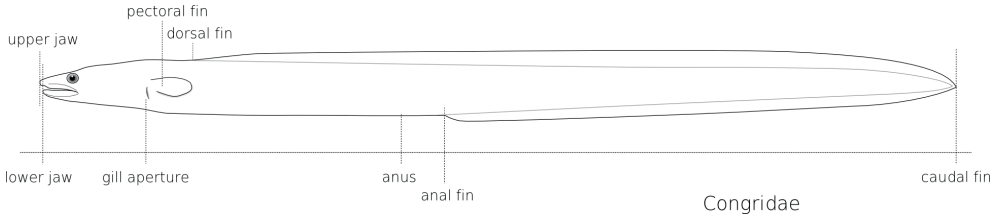
Order Lepidosireniformes / Family Protopteridae – African lung fishes

The lungfish lives in fresh waters and are eaten mainly in Africa at a size of 60–120 cm (Goudswaard *et al*. 2002). The same report claimed that the meat is locally either highly appreciated or strongly disliked. Several studies have demonstrated that lungfishes are more related to tetrapods than to fishes, despite that they still have both gills and scales. Unlike freshwater eels, the African lungfish have large scales and long, meaty thread-like appendages, homologous to the pectoral and pelvic fins.



Order Anguilliformes / Family Muraenesocidae – Pike congers

The pike congers occur in the trade in countries around the Indian and Pacific Oceans. Catch statistics are reported separately for at least *Muraenesox cinereus*; FAO-statistics reported by e.g. South Africa, Pakistan, India, and China. Pike congers are eel shaped but have a head with slender pointed, jaws with teeth, quite unlike that of freshwater eels where the teeth are concealed by thick lips. The lower jaw has a typical bump, fitting in a notch of the upper jaws. The gill openings are large, extending from the pectoral fin bases to near the ventral midline, almost meeting in the middle. All pike congers are strictly marine.



Order Anguilliformes / Family Congridae – Conger eels

The conger eels are common in the trade worldwide and superficially similar to the freshwater eels. International trade is largely restricted to frozen adults (> 500 mm TL). All life stages of conger eels are strictly associated with marine habitats, even if a few species may occasionally enter brackish waters. Conger eels are readily identified by (1) the long dorsal fin nearly reaching the pectoral fin; (2) have an upper jaw longer than the lower jaw; and (3) a complete lack of scales. Some species of conger eels exceed two and a half meters in total length and 60 kg. Live conger eels have very powerful jaws and should be handled with caution. The Pacific conger species, *Conger myriaster*, has a conspicuous lateral line pores surrounded by white spots whereas the Atlantic species have a uniform grey brown colour.

Order Anguilliformes / Family Muraenidae – Moray eels

Moray eels are found in commercial trade world-wide. In Europe, the moray eels are included in the catch statistics of e.g. Portugal. Morays are not the staple food in any country, and they never dominate catch statistics. Moray eels also occur in the aquarium trade. Moray eels are readily distinguished from freshwater eels (Anguillidae) by (1) the lack of pectoral fins (yet, leptocephalus larvae of Muraenidae have pectoral fins) and (2) the big gape (eye at mid point from snout tip to gape angle). There are about 200 species of moray eels, which typically are near shore living marine fish. At least two species visit brackish or fresh water (*Gymnothorax polyuranodon* and *G. tile*, both from the Indo-Pacific region) and are occasionally found in the aquarium trade.

Order Anguilliformes / Family Ophichthidae – Snake eels

The snake eels are a group of mainly marine, often with striking coloration. Snake-eels occur from the equator to warm temperate regions. Pectoral fins may be present or absent. Most species have an upper jaw distinctly longer than the lower jaw and an expanded gill cavity much wider than the head and body. The posterior nostril is uniquely located below the eye or in the mouth cavity, unlike any other anguilliform possibly found in the trade.

Order Anguilliformes / Family Synaphobranchidae – Cutthroat eels

The cutthroat eels live at great depths in the Atlantic, Indian and Pacific oceans. Opening of gills low on body, below or at the insertion of pectoral fin. Pectoral fin absent in a few species. The lower jaw never longer than upper jaw as in freshwater eels.

Order Siluriformes / Family Clariidae – Eel catfishes

The eel catfish, Claridae, is a group of about 100 freshwater species found in tropical and subtropical regions of Africa and Asia. Many species grow to over a meter and may superficially resemble an eel, which has also given them their English name. Eel catfish are readily distinguished from freshwater eel by (1) long barbels in catfish (absent in eels); (2) pectoral fins with hard

(poisonous) spines (absent in freshwater eels); (3) pelvic fins present, right in advance of anal fin (pelvic fins absent in freshwater eels); (4) caudal fin distinct in most species (confluent with both dorsal and anal fins in freshwater eels) and (5) head flattened, much wider than high (whereas near cylindrical in freshwater eels).

Order Siluriformes / Family Plotosidae – Sea catfishes

The sea catfishes, Plotosidae, is a group of about 30 species found in both freshwater and nearshore marine habitats in tropical and subtropical regions world-wide. Most species probably won't be mistaken for freshwater eels. Some species like the eeltail catfishes may, however, be mistaken for an eel. Sea catfish are readily distinguished from freshwater eel by (1) long barbels (absent in eels); (2) pectoral fins with hard (poisonous) spines (absent in freshwater eels); (3) pelvic fins present, right in advance of anal fin (pelvic fins absent in freshwater eels); (4) dorsal fin small, high and situated right behind the head (invariably long and low and remote from head in freshwater eels) and (5) caudal fin distinct or confluent with anal fins (always confluent with both dorsal and anal fins in freshwater eels).

Order Synbranchiformes / Family Synbranchidae – Swamp eels

The swamp eels are small group of about 15 eel-like species found in tropical and subtropical freshwaters of South and Central America and Asia. Most species grow to almost a meter and may superficially resemble an eel, which has also given them their English name. The most marked species is *Monopterus albus*. The swamp eels are readily distinguished from freshwater eels by (1) complete lack of pectoral fins (distinct in freshwater eels); (2) anus located behind middle of body (located in advance in freshwater eels); (3) gill membranes fused with gill opening a small slit or pore in the middle, under the head (present on both sides in freshwater eels).

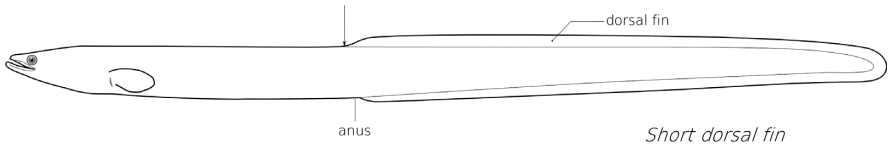
Order Synbranchiformes / Family Mastacembelidae – Spiny eels

The Mastacembelidae are freshwater fishes found in tropical and subtropical parts of Africa and Asia. They can be distinguished by (1) a long pointed upper jaw, much longer than the lower jaw (lower jaw always the longer in freshwater eels); (2) a series of small spines along back from head towards dorsal fin; and (3) distinct caudal fin (always confluent with both dorsal and anal fin in freshwater eels).

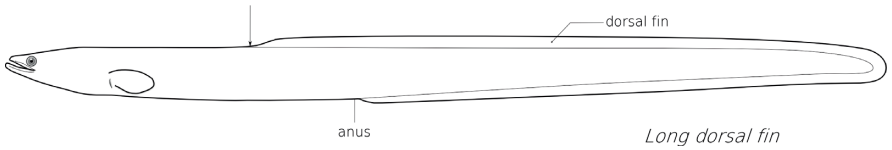
(2) Key to glass eels and young freshwater eels

This key is designed to work on intact specimens smaller than 200 mm total length (TL) and requires a sharp-legged vernier caliper graded to 0.1 mm and a binocular stereomicroscope. For statistical reasons a sample size larger than 15 is recommended. Please also refer to frequency tables in Appendix. Caution: This key may not work in a mixed species sample. For corroboration, identifications should be followed up with a molecular analysis (described below).

1a	Dorsal n short, typically situated above or near anus	*A. obscura*, *A. bicolor*, or *A. australis*
1b	Dorsal n long, anterior margin more than 5% of TL in advance of anus	2



Short dorsal fin



Long dorsal fin

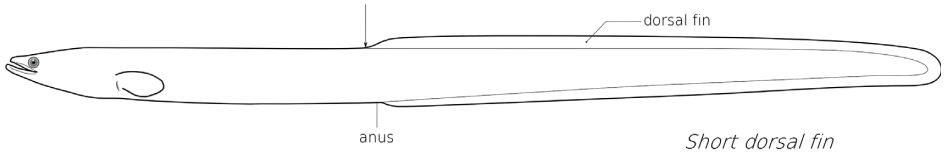
2a	Sample median (N≥15) of total vertebrae 102–110	*A. bengalensis*, *A. borneensis*, *A. celebesensis*, *A. interioris*, *A. marmorata*, *A. mossambica*, *A. obscura*, *A. reinhardti*, or *A. rostrata*
2b	Sample median (N≥15) of total vertebrae 112–117	3
3a	Sample median (N≥15) of prehaemal vertebrae 41–42	*A. megastoma*
3b	Sample median (N≥15) of prehaemal vertebrae 43–46	4
4a	Sample median (Nv15) of postanal length 5.6–6.0 times dorsoanal distance	*A. dieffenbachi* [1], or *A. japonica*
4b	Sample median (N≥15) of postanal length 5.0–5.2 times dorsoanal distance	*A. anguilla*

[1] Apart from small quantities of glass eels that can be caught for research purposes, it is not legal in New Zealand to catch or export glass eels, or catch any eel below the minimum commercial size of 220 g (Jellyman 2007). The length of *Anguilla dieffenbachi* at 220 g typically is about 500 mm TL, as estimated from data provided by Chisnall (2000).

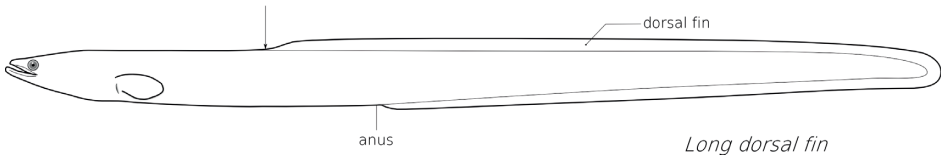
(3) Key to juvenile and adult freshwater eels

Identification of eel samples using morphology is often the fastest way of eel identification, and can often be done in short time with the right equipment available. This key is designed to work with a sample of at least 15 intact specimens larger than 200 mm total length (TL) and requires radiographic data and a binocular stereo microscope. Please also refer to frequency tables in Appendix. For corroboration, identifications should be followed up with a molecular analysis (described below).

1a	Dorsal n short, typically situated above or near anus	2
1b	Dorsal n long, anterior margin more than 5% of TL in advance of anus	4

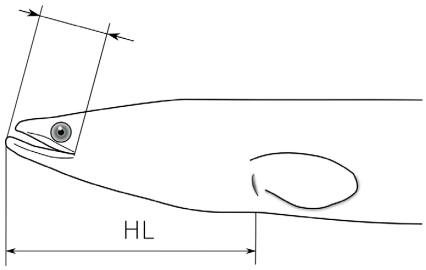


Short dorsal fin

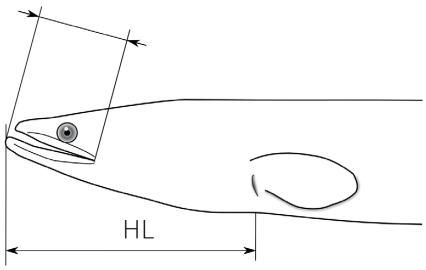


Long dorsal fin

2a	Mouth large, lower jaw about one third of head length	*A. obscura*
2b	Mouth small, lower jaw about one fourth of head length	3



Small mouth



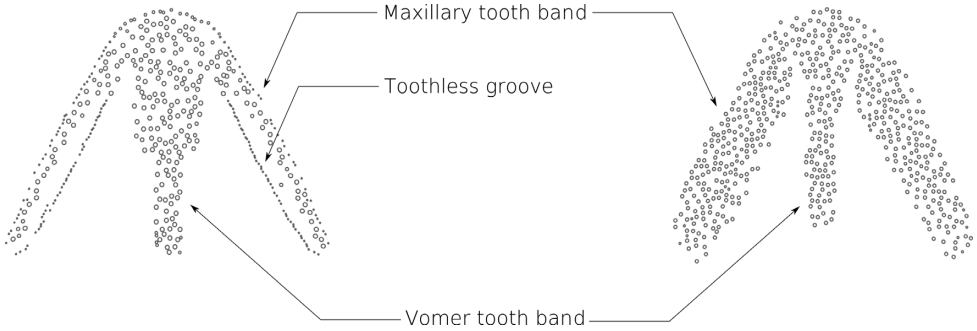
Large mouth

3a	Sample median (N≥15) of prehaemal vertebrae 42–44 (range 41–45)	*A. bicolor*
3b	Sample median (N≥15) of prehaemal vertebrae 45–47 (range 44–48)	*A. australis*
4a	Mouth large, lower jaw about one third of head length	5
4b	Mouth small, lower jaw about one fourth of head length	12
5a	Coloration marbled	6
5b	Coloration plain	9

plain coloration

marbled coloration

6a	Vomer tooth band broader in the middle than maxillary bands	7
6b	Maxillary tooth bands broader than vomer band, without groove	8



7a	Sample median (N≥15) of total vertebrae 105-107 (range 100–110) sample median (N≥15) of anodorsal distance 15.5–16.5% of TL (range 12.0–18.9% of TL)	*A. marmorata*
7b	Sample median (N≥15) of total vertebrae 109–112 (range 106–115) sample median (N≥15) of anodorsal distance 10.5–12.5% of TL (range 7.0–14.9% of TL)	*A. bengalensis*
8a	Sample median (N≥15) of total vertebrae 112–114 (range 108–116)	*A. megastoma*
8b	Sample median (N≥15) of total vertebrae 103–106 (range 101–108)	*A. celebesensis* or *A. interioris*
9a	Sample median (N≥15) of total vertebrae 102–106 (range 100–108), sample median (Nv15) of prehaemal vertebrae 40–41 (range 39–42)	10
9b	Sample median (N≥15) of total vertebrae 112–114 (range 108–116)	11
10a	Maxillary tooth bands with toothless groove	*A. borneensis*
10b	Maxillary tooth bands without groove	*A. mossambica*
11a	Vomer tooth band broader in the middle than maxillary bands	*A. dieffenbachi*
11b	Maxillary tooth bands broader than vomer tooth band	*A. megastoma*
12a	Coloration marbled	*A. reinhardti*
12b	Coloration plain	13
13a	Sample median (N≥15) of total vertebrae 106–108 (range 103–111)	*A. rostrata*
13b	Sample median (Nv15) of total vertebrae 114–117 (range 110–119)	14
14a	Maxillary tooth bands with toothless groove Sample median (N≥15) of postanal length 5.6–6.0 times dorsoanal distance	*A. japonica*
14b	Maxillary tooth bands without toothless groove Sample median (N≥15) of postanal length 5.0–5.2 times dorsoanal distance	*A. anguilla*

Molecular identification

Molecular identification is unlike morphology-based methods suitable for all life stages (eel eggs, larvae, glass eels, and adults) as well as processed eels (e.g. decapitated, smoked, frozen, cooked, canned, etc.). Routine identification of eel species using molecular markers may be done at any suitable laboratory, and with a result normally available within a week.

There are several alternative molecular methods by which one may identify eels. Hubalkova *et al*. (2007) listed and discussed several protein and DNA molecular methods available for fish identification with a focus on gadiform species (cod, hake, ling, etc.). Rasmussen and Morrissey (2008) summarized the recent advances in the identification of fish with a comprehensive overview of the alternative molecular methods available and discussed their suitability in different situations. The current document, however, focuses on methods which have been applied in the identification of *Anguilla* species, but recognizes the availability of several other relevant methods.

Authenticity

Most molecular methods require the comparison with sequences taken from authenticated specimens, i.e. from specimens with a trusted identity. Due to the wide-spread stocking of glass eels for decades around the world, this has become more difficult. For example, Okamura (2001, 2004) could determine that up to 93% of all eels sampled in a Japanese lake were the European eel with the remaining 7% the native Japanese eel. Similar studies have shown that the American eel (Frankowski *et al*. 2008) and the Japanese eel (Kirk 2003) have been found in European natural waters and/or aquaculture in Europe.

Several projects have addressed this issue and raised the criteria for the inclusion of molecular sequences in their databases. FishTrace (www.fishtrace.org) and FishBOL (www.fishbol.org; and CBOL, www.boldsystems.org) are projects which have sequences from authenticated specimens represented with voucher specimens stored in larger natural history collections and available for later revalidation. Data from these projects are typically also available through GenBank (www.ncbi.nlm.nih.gov), the largest repository of molecular sequences useful for fish identification with more than 1,500 sequences labeled "*Anguilla*".

Laboratories working with many eel species should always consider the risk of DNA contamination from other close related species. Aoyama *et al* (2001) reanalysed some previously published sequences and suggested that the original identification submitted to GenBank was wrong; "cross-contamination of DNA samples appears to be most likely explanation". Scientific names

of organisms also often change over time and for many reasons. This leads to a mismatch between the scientific names submitted to public databases and current usage, unless the database is updated. The sequence Aoyama (2001) found wrongly identified by the submitter, AJ244830, still is labelled with the erroneous name.

While molecular methods are strong, they should (if possible) always be coupled with a morphological analysis, for independent corroboration. Table 1 lists the scientific names of freshwater eels found in GenBank and their current usage (e.g. in this document).

Table 1. Scientific name used at GenBank and those used in this document.

Scientific name used in GenBank	Scientific name used in this document	Scientific name used in GenBank	Scientific name used in this document
A. anguilla	*A. anguilla*	*A. japonica*	*A. japonica*
A. australis	*A. australis*	*A. malgumora*	*A. borneensis*
A. australis australis	*A. australis*	*A. marmorata*	*A. marmorata*
A. australis schmidti	*A. australis*	*A. megastoma*	*A. megastoma*
A. bengalensis	*A. bengalensis*	*A. mossambica*	*A. mossambica*
A. bengalensis labiata	*A. bengalensis*	*A. nebulosa*	*A. bengalensis*
A. bicolor	*A. bicolor*	*A. nebulosa nebulosa*	*A. bengalensis*
A. bicolor bicolor	*A. bicolor*	*A. obscura*	*A. obscura*
A. bicolor pacifica	*A. bicolor*	*A. reinhardti*	*A. reinhardti*
A. celebesensis	*A. celebesensis*	*A. rostrata*	*A. rostrata*
A. dieffenbachi	*A. dieffenbachi*	*A. sp.*	–
A. interioris	*A. interioris*		

Table 2. Comparison of DNA-based methods used in fish species identification for the prevention of commercial fraud. Adapted from Bossier (1999), Liu and Cordes (2004), Rasmussen and Morrissey (2008), and Wong and Hanner (2008).

DNA-based method	Standardized across taxa	Loci examined	Robustness to DNA degradation	Interlaboratorial reproducibility	Cost	Intraspecies variation errors
DNA barcoding	Yes	Single	Medium-high	High	High	Low
DNA sequencing and phylogenetic mapping	No	Single	Medium-high	High	High	Low
Species-specific primers and multiplex PCR	No	Single	Medium-High	High	Medium	Medium
Restriction fragment length polymorphism (RFLP)	No	Single	Medium-high	High	Medium	Medium
Single stranded conformational polymorphism (SSCP)	No	Single	Medium-high	Medium	Medium	Low-medium
Random amplified polymorphic DNA (RAPD)	No	Multiple	Low-medium	Low-medium	Medium	Low-medium
Amplified fragment length polymorphism (AFLP)	No	Multiple	Low-medium	Medium-high	Medium-high	Low-medium

DNA analysis

Sequence data useful for fish identification may be extracted from both DNA and proteins (Hubalkova *et al*. 2007), but DNA-based studies have several advantages over proteins. DNA is typically more heat tolerant than proteins and not dependent on the kind of tissue or age of the individual (Itoi *et al*. 2005, Chapela *et al*. 2007). DNA has also been shown to contain more species specific information suitable for species identification (Rasmussen and Morrissey 2008). Both mitochondrial DNA (mtDNA) and nuclear DNA (nDNA) have been used successfully in the identification of fish species but mtDNA often is preferred over nDNA as it is more abundant, more species specific, has no heterozygous genotypes (Sezaki *et al*. 2005), and also is more heat tolerant (Bossier 1999). When the protocol is standardized to work on a larger number of taxa it is often referred to as 'barcoding'.

Sampling

Tissue samples for fish identification typically come from muscle (Lin *et al*. 2001, Sezaki *et al*. 2005), liver (Aoyama *et al*. 2001, Han *et al*. 2002), or fin clips (Lin *et al*. 2001, Zilberman *et al*. 2006). Fish typically have very little blood and its sampling is therefore not an option. Tissue may be removed from the fish using clean scalpel, with blade replacement after each sampled indivdual. Each tissue sample must be stored separately, with explicit annotations (date, time, place, size, species, origin, running number, etc.). The samples may be stored dry or in vials with 95–99% ethanol, at room or refrigerator temperature for a short term storage before analysis. Unless ethanol is available, moist tissue samples should be air dried within hours on filter paper or paper towels before put in sealed vials due to the risk of fungal and bacterial attack. There has been reports on difficulties in extracting DNA from tissue collected in the field and stored in warm climate for long before reaching the laboratory. Due to the risk of mixed species shipments it is recommended to sample at least 15 specimens randomly for combined molecular and morphological analyses. In case of several shipment containers, at least two such samples of 15 specimens each are recommended. Please also confer with discussion at Morphological identification.

Extraction

DNA extraction includes several steps, including digestion and purification. Tissue samples are first minced, and then digested in a buffer solution (Aoyama *et al*. 2001). Purifications have successfully been using phenol/chloroform/isoamyl alcohol (e.g. Aoyama *et al*. 2001, Watanabe *et al*. 2004b, Minegishi *et al*. 2005), 5% chelex extractions (Watanabe *et al*. 2004b), and/or commercial extraction kits (Minegishi *et al*. 2005). Extraction of DNA may take several hours to overnight.

Amplification

The amount of extracted DNA typically is very small, and too small for many modern analyses. Therefore, the DNA is amplified using PCR (polymerase chain reaction). The method involves heating, cooling, and reheating the DNA in about 30–50 cycles which builds up the amount of DNA to usable quantities. Longer sequences, like the entire mitochondrial genome, may be performed in several steps (Mingegishi *et al*. 2005). Amplification takes several hours.

Primers

Some sequences evolve faster and others are more conservative where the fast mutating sequences may exhibit intraspecific polymorphisms. Therefore it is important to select primers specific to sequences with a relevant mutation rate (Sevilla *et al*. 2007). Minegishi *et al*. (2005) have analysed the relationships of all freshwater eel species using the entire mitochondrial genome and provided over one hundred forward and reverse Long-PCR and PCR primers with different specificity (fish, anguilliform, anguillidae, species), many of which were newly designed. While the entire genome was examined there are thus also primers for all 13 protein coding genes (Cytochrome b, 12S rRNA, 16S rRNA, COI, etc.), for all species of *Anguilla*. Primers typically have a storage longevity for many years, and are known to last for more than ten years. At the time of writing, stock solutions cost about 10 € (thus 20 € for both forward and reverse primers) and may last for more than a thousand analyses and can be prepared and stored in advance at accredited institutions awaiting Customs samples.

Recommended protocols

The Consortium for the Barcode of Life (CBOL, www.boldsystems.org) provides a standard genetic marker based on the mitochondrial cytochrome oxidase subunit I (COI) for all organisms (Wong and Hanner 2008). Cytochrome oxidase I (COI) as the molecular marker of choice offers several advantages:

1. the protocol is robust, reliable and easily replicable in any standard molecular laboratory
2. the primers generate a single, strong band with minimal primer dimers
3. at least one sequence per species is already available in the CBOL and GenBank as part of the complete mitochondrial genome
4. the CBOL initiative uses authenticated specimens with vouchers stored in public collections
5. the protocol proved to work consistently across all fishes (e.g. Ward *et al*. 2005)
6. allows positive identifications in mixed species samples
7. many more sequences will be released in the near future as part of the growing worldwide barcoding initiative which will increase the discriminability of the locus, possibly also below the species level

The following protocol for the amplification of the "barcoding" region of the cytochrome c oxidase subunit I (Ward *et al*. 2005) has been used successfully for the barcoding project for the Swedish vertebrates at the Molecular Systematics Laboratory, Swedish Museum of Natural History (Dr. Dario Zuccon, pers. comm.). The COI region is amplified as a single fragment using the pair of primers:

```
FishF1 (3'-TCAACCAACCACAAAGACATTGGCAC-5')
FishR1 (3'-TAGACTTCTGGGTGGCCAAAGAATCA-5')
```

The amplification profile consists of an initial denaturation of 2 min. at 94°C, followed by 35 cycles of denaturation for 30 secs at 94°C, annealing 30 sec. at 54°C, extension 60 sec. at 72°C, and a final extension of 10 min. at 72°C. The same primer couple is used for both amplification and sequencing. The product is 707 base pairs.

It is also suggested, as a second alternative strategy, and as used by Frankowski *et al*. (2008) for discrimination between *Anguilla anguilla* and *A. rostrata*, and based on Kessing *et al*. (1989), to use a portion of the third domain of the 16S rRNA gene. The following protocol has been successfully used at the Molecular Systematics Laboratory, Swedish Museum of Natural History (Dr. Dario Zuccon, pers. comm.). The 16S rRNA region is amplified as a single fragment using the pair of primers:

```
16Sar (5'-CGCCTGTTTATCAAAAACAT-3')
16Sbr (5'-CCGGTCTGAACTCAGTCACGT-3')
```

The amplification profile consists of an initial denaturation of 5 min. at 94°C, followed by 35 cycles of denaturation for 30 secs at 94°C, annealing 30 sec. at 55°C, extension 60 sec. at 72°C, and a final extension of 5 min. at 72°C. The same primer couple is used for both amplification and sequencing. The product is 638 base pairs.

A third strategy should include the cytochrome b gene, as used and advocated by Lin *et al*. (2002) and Hwang *et al*. (2004) for freshwater eel identification. Cytochrome b was specifically mentioned by Rasmuseen and Morrissey (2008) as "prominent" and is also the most abundantly sequenced gene for freshwater eels in GenBank. Sevilla *et al*. (2007) described in detail a set of 21 PCR primers and amplification conditions developed to "barcode practically any teleost fish species according to their mitochondrial cytochrome b and nuclear rhodopsin gene sequences". Their method was successfully tested in more than 200 marine fish species. According to GenBank, the nuclear rhodopsin gene is unfortunately still only sequenced for a few specimens of *Anguilla anguilla* and one specimen of *A. japonica*.

Storage

It is recommended that all sampled material is ultimately stored at institutions with an official long term duty, well established protocols and routines for handling and long-term storage of natural history objects, such as natural history museums and some universities (O'Sullivan *et al*. 2007). Longer term storage (more than 10 years) of DNA characteristically requires deep freezers at –80°C or colder (O'Sullivan *et al*. 2007, Santella and Hankinson 2008). Depending on the volume of the Customs samples, the additional cost for storage of tissue samples may be expected to be marginal.

Identification

The resulting nucleotide sequence of the COI, 16S rRNA, or the cytochrome b genes may immediately be compared with species obtained in previously published data through the web pages of BLAST (Altschul *et al*. 1990, http://blast.ncbi.nlm.nih.gov) or BOLD (Ratnasingham and Hebert 2007, www.boldsystems.org). Using any of the three suggested genes (COI, 16S rRNA, or Cytochrome b genes for BLAST, only COI for BOLD) will also allow the positive identification of any other fish species in the Customs sample (if the sequence of the species is available in GenBank or BOLD). This is most important in the case of mixed species samples.

There has been some concern for nuclear mitochondrial pseudogenes ("numts", nonfunctional copies of mtDNA in the nucleus) that have been found in some clades among eukaryotic organisms (Song *et al*. 2008). Recent claims that these have not been found in fish (Song *et al*. 2008, Hubert *et al*. 2008) have overlooked the study by Teletchea *et al*. (2005) which found nuclear copies of the COI gene in two gadid species. In order to minimize the risks of "numts", Song *et al*. (2008) recommended to pay attention to PCR "Ghost bands", "Double peaks" as well careful comparison with already published data through BLAST.

For additional reliability of species identity one may perform a full phylogenetic analysis (Lin *et al*. 2002, Rasmuseen and Morrissey 2008). Here one may use one of the appropriate programs listed by Prof. Joseph Felsenstein, Department of Genome Sciences, University of Washington, Seattle, USA (http://evolution.genetics.washington.edu/phylip/software.html). Recent studies typically use one or several algorithms (Maximum-Parsimony, Maximum-Likelihood, or Bayesian analysis) implemented in software such as MEGA, MrBayes, and PAUP (details for each all listed in the link above).

Many authors (e.g. Lin *et al*. 2002, Sevilla *et al*. 2007) recommend the application of two or more genes which combined increase the robustness of identifications. Using the three genes recommended above COI + 16S rRNA + Cytochrome b should positively identify any eel sample, whether it is a mixed species sample or not. The additional work and cost may be considered marginal in light of the increased accuracy and confidence.

Unique marker

A reanalysis of the cytochrome b sequences of all 125 specimens of *Anguilla anguilla* already in GenBank reveals the existence of a species specific marker useful for the identification of *Anguilla anguilla* versus not only all other anguilliforms, but also all other organism sequenced to date. The marker is only 47 basepairs and is located between 14,735–14,781st position of the complete *Anguilla anguilla* mitochondrial genome (AP007233, Minegishi *et al*. 2005). The sequence is

CTTTACTACGGCTCATACCTTTACATAGAAACATGAAACATTGGAGT

and is not variable in any of the 125 specimens of *Anguilla anguilla* which come from 12 different laboratories and collected at more than 17 different localities in Morocco, Italy, Spain, France, UK, and Sweden (see Table 4). A BLAST search using the 47 base-pairs gives 100% correct hit rate for *A. anguilla* as shown in Figure 74.

A comparison of the relative similary in per cent, between the unique *A. anguilla* marker (with 100% self similarity) and more distantly related taxa, still within the Anguilliformes, is presented in Table 3 and shows a falling degree of similarity from 91.4% to 25.8% using the Taxonomy Report of the BLAST home page. The similarity outside the Anguilliformes is as expected lower, yet with the the highest (85%) similarity shown by the unrelated cichlid fish *Astronotus* spp. (data not shown).

DNA in processed food typically is degraded during heating and the severity may also depend on the liquid media of the food (e.g. brine, oil, vinegar, etc.). However, DNA fragments as long as 300 bp can still be recovered following sterilization and fragments shorter than 150 basepairs typically are almost always recovered (Chapela *et al*. 2007).

A newly developed primer pair which results in a 168 basepair long product and which includes the 47 basepair region was tested on tissue samples from two additional eel specimens. The first tissue sample comes from an ethanol preserved glass eel specimen collected on the Swedish west coast, near Halmstad (museum catalogue number NRM 59516). The second tissue sample is from the crispy tip of the pectoral fin of a smoked eel bought at a retailer shop in Stockholm (museum catalogue number NRM 60127). The 168 basepair region is amplified as a single fragment using the primer pair:

Cytb-AngF GGATGAYTAATYCGCAACYTACATGC
Cytb-AngR GGTTGGTAATTACTGTAGCACCTCAG

Amplification used a hot-start touchdown PCR, with an initial denaturation at 95°C for 5 min, followed by 4 cycles of 95°C for 30 s, 63°C for 30 s, 72°C for 30s, and another 4 cycle phase and one 26 cycle phase with identical temperatures and intervals except for the annealing temperature was decreased to 61°C and 59°C, respectively. The thermocycling program was ended by 72°C for 5 min.

It should be noted that any cytochrome b primer pair which includes the 47 base pair region should work. The long flanking regions by the current primer pairs ensure high readability with current sequencing machines. Yet, they also leave the door open for development of primer pairs with even shorter resulting products.

Table 3. Relative similarity in per cent (%) of the unique *Anguilla anguilla* cytochrome b marker and sequences in other anguilliforms. Data extracted from the BLAST Taxonomy Report.

Anguilliformes			
Anguilla anguilla	100.0	*Gymnothorax flavimarginatus*	49.5
Anguilla celebesensis	91.4	*Gymnothorax meleagris*	49.5
Anguilla dieffenbachi	91.4	*Enchelycore anatina*	45.2
Anguilla japonica	82.8	*Gymnothorax polygonius*	45.2
Anguilla rostrata	82.8	*Gymnothorax chilospilus*	43.0
Anguilla australis	74.2	*Gymnothorax eurostus*	43.0
Anguilla australis australis	74.2	*Gymnothorax favagineus*	43.0
Anguilla australis schmidti	74.2	*Gymnothorax fimbriatus*	43.0
Anguilla borneensis	74.2	*Gymnothorax isingteena*	43.0
Anguilla marmorata	74.2	*Gymnothorax javanicus*	43.0
Anguilla obscura	74.2	*Gymnothorax reticularis*	43.0
Anguilla bengalensis labiata	69.9	*Gymnothorax rueppellii*	43.0
Anguilla nebulosa nebulosa	69.9	*Conger myriaster*	40.9
Muraena robusta	61.3	*Gymnothorax reevesii*	34.4
Muraena augusti	59.1	*Gymnothorax afer*	32.3
Gymnothorax hepaticus	53.8	*Muraenesox cinereus*	30.1
Gymnothorax maderensis	53.8	*Muraenesox bagio*	28.0
Muraena helena	53.8	*Gymnothorax berndti*	25.8
Gymnothorax kidako	51.6	*Gymnothorax margaritophorus*	25.8
Gymnothorax pseudothyrsoideus	51.6	*Gymnothorax unicolor*	25.8
Moringua edwardsi	51.6	*Muraena melanotis*	25.8

Table 4. Listing of all 125 specimens of *Anguilla anguilla* in GenBank and two specimens examined in this study, all of which also have the 47 basepair *Anguilla anguilla* species specific genetic marker. Museum abbreviations are MNHN (Museum national d'Historire Naturelle, Paris), NRM (Swedish Museum of Natural History), and TFMC (Tenerife Museum of Natural History).

GenBank accession	Submission date	Geographic origin	N	Voucher	Literature source or submitter
D28775	19940302	Not stated	1	–	Yuji (unpublished)
D84302	19960404	Not stated	1	–	Aoyama & Tsukamoto (1997)
AF006714	19970605	England, Severn	1	–	Lin *et al.* (2001)
AF006715	19970605	Sweden, Viskan River	1	–	Lin *et al.* (2001)
AB021776	19981223	France	1	–	Aoyama *et al.* (2001)
AF165069	19990706	Not stated (Swiss retailer)	1	–	Wolf *et al.* (2000)
AF172394	19990727	Not stated (Austrian zoo)	1	–	Parson *et al.* (1999)
AF368240	20010405	Ireland, Burrishoole River	1	–	Daemen *et al.* (2001)
AF368243	20010405	Ireland, Burrishoole River	6	–	Daemen *et al.* (2001)
AF368245	20010405	Ireland, Burrishoole River	1	–	Daemen *et al.* (2001)
AF368247	20010405	Ireland, Burrishoole River	7	–	Daemen *et al.* (2001)

GenBank accession	Submission date	Geographic origin	N	Voucher	Literature source or submitter
AF368248	20010405	Ireland, Burrishoole River	1	–	Daemen *et al.* (2001)
AF368249	20010405	Ireland, Burrishoole River	1	–	Daemen *et al.* (2001)
AF368250	20010405	Ireland, Burrishoole River	2	–	Daemen *et al.* (2001)
AF368252	20010405	Ireland, Burrishoole River	2	–	Daemen *et al.* (2001)
AF368240	20010405	Italy, Arno River	1	–	Daemen *et al.* (2001)
AF368241	20010405	Italy, Arno River	1	–	Daemen *et al.* (2001)
AF368243	20010405	Italy, Arno River	4	–	Daemen *et al.* (2001)
AF368244	20010405	Italy, Arno River	1	–	Daemen *et al.* (2001)
AF368245	20010405	Italy, Arno River	1	–	Daemen *et al.* (2001)
AF368246	20010405	Italy, Arno River	1	–	Daemen *et al.* (2001)
AF368247	20010405	Italy, Arno River	14	–	Daemen *et al.* (2001)
AF368240	20010405	Morocco, Sebou River	1	–	Daemen *et al.* (2001)
AF368243	20010405	Morocco, Sebou River	6	–	Daemen *et al.* (2001)
AF368246	20010405	Morocco, Sebou River	1	–	Daemen *et al.* (2001)
AF368247	20010405	Morocco, Sebou River	12	–	Daemen *et al.* (2001)
AF368250	20010405	Morocco, Sebou River	1	–	Daemen *et al.* (2001)
AF368252	20010405	Morocco, Sebou River	1	–	Daemen *et al.* (2001)
AF368239	20010405	Sweden, Viskan River	1	–	Daemen *et al.* (2001)
AF368240	20010405	Sweden, Viskan River	2	–	Daemen *et al.* (2001)
AF368242	20010405	Sweden, Viskan River	1	–	Daemen *et al.* (2001)
AF368245	20010405	Sweden, Viskan River	2	–	Daemen *et al.* (2001)
AF368246	20010405	Sweden, Viskan River	2	–	Daemen *et al.* (2001)
AF368247	20010405	Sweden, Viskan River	10	–	Daemen *et al.* (2001)
AF368251	20010405	Sweden, Viskan River	1	–	Daemen *et al.* (2001)
AF368252	20010405	Sweden, Viskan River	1	–	Daemen *et al.* (2001)
AF368253	20010405	Sweden, Viskan River	1	–	Daemen *et al.* (2001)
AF368238	20010405	United Kingdom, Severn	1	–	Daemen *et al.* (2001)
AF368240	20010405	United Kingdom, Severn	1	–	Daemen *et al.* (2001)
AF368243	20010405	United Kingdom, Severn	7	–	Daemen *et al.* (2001)
AF368247	20010405	United Kingdom, Severn	7	–	Daemen *et al.* (2001)
AF368250	20010405	United Kingdom, Severn	2	–	Daemen *et al.* (2001)
AF368252	20010405	United Kingdom, Severn	1	–	Daemen *et al.* (2001)
AF368254	20010405	United Kingdom, Severn	1	–	Daemen *et al.* (2001)
AP007233	20040809	France, Vilaine	1	–	Minegishi *et al.* (2005)
EF427617	20070125	Spain, Galician coast	1	TFMC BMVP/1298	www.fishtrace.org
EF427618	20070125	Spain, Galician coast	1	TFMC BMVP/1299	www.fishtrace.org
EU223996	20071016	France, river la Loire	1	MNHN 2004-1449	www.fishtrace.org
EU223997	20071016	France, river la Loire	1	MNHN 2004-1450	www.fishtrace.org
EU315235	20071203	Not stated	1	–	Frankowski *et al.* (2008)
EU315236	20071203	Not stated	1	–	Frankowski *et al.* (2008)
EU315237	20071203	Not stated	1	–	Frankowski *et al.* (2008)
EU315238	20071203	Not stated	1	–	Frankowski *et al.* (2008)
EU492326	20080214	Sweden, Strömstad	1	NRM 49647	www.fishtrace.org
EU492327	20080214	Sweden, Strömstad	1	NRM 49646	www.fishtrace.org
FN263189	20090318	Sweden, Halmstad	1	NRM 59516	This study
FN263190	20090318	Not stated (Swedish retailer)	1	NRM 60127	This study
			127		

Trade

The freshwater eels are used for food throughout their distribution and are sold fresh, smoked, canned, cooked, or, live for stocking, either as glass eels or as yellow and silver eels. All species of *Anguilla* are of economic interest, whether locally or internationally. Freshwater eels are normally not found in the aquarium trade.

A large portion of the eel fishery of adult eels takes place in fresh water or near the coast. The traditional fishing gears in Europe for yellow and silver eels include long-lines, gill-nets and traps such as fyke-nets and other cages with one-way entrances. Historically many other techniques have been used, such as tridents, spears, harpoons, cast-nets, etc.

The majority of European glass eels arrive at the Bay of Biscay (Dekker 2000) which is also supported by computer simulations (Kettle and Haines 2005). Glass eels are harvested commercially at river mouths and in estuaries along the European west coast, whereas the eel fisheries in northern Europe is targeted on adults. 87% of all glass eels are collected in the Biscay area (Dekker 2000). The season starts in October when the first glass eels arrive to the Iberian peninsula and successively continues north well into June in the British Isles, with a peak in the market in February (Frost 2001). The glass eels of *Anguilla anguilla* use a tidal stream transport for entering the rivers (Creutzberg 1958, Gascuel 1986), which also is a behaviour observed in most temperate and tropical *Anguilla* species (Briand *et al*. 2005).

The glass eels are largely collected for export to Asia (Frost 2001) where seedstocks often (up to 60–80%) are composed of European glass eels (Ringuet *et al*. 2002, Ottolenghi *et al*. 2004). The decline in the recruitment has lead to a decrease in recent years in the export of glass eels from a peak of about 300 tonnes (Ringuet *et al*. 2002) to below 100 tonnes (ICES 2008). An export of 100 metric tonnes of glass eels corresponds to 300-400 million individual glass eels marketed in East Asia. The prices for glass eels fluctuates rapidly depending on catch success and demand, currently between 400 and 700 € per kg. Each individual glass eel then has a market value of about 0.2 € in Europe, whereas it is higher in East Asia.

The number of indivudual eel specimens is not directly reflected in catch statistics. Yet, the number of individual adult eels produced in the world can be calculated using the catch statistics 15,000 metric tonnes (FAO 2006, Table 5; discrepancies between various report statistics have been noted by ICES 2008a) and an estimated average market weight of 120–600 g, or up to about 6 individual eels per kilogramme (FAO 2005, www.fao.org/fishery/culturedspecies/Anguilla_anguilla; retrieved 18 Oct 2008). That calculates to at most 130 million adult marketed individual *Anguilla anguilla* per year in the world.

The number of produced eels in Europe, using the same calculation, and catch statistics (see Table 7) in metric tonnes from Eurostat (February 2007, http://epp.eurostat.ec.europa.eu; retrieved 18 Oct 2008) for "Region R27 – North-east Atlantic" gives about 17 million adult individual *Anguilla anguilla* per year in Europe. In other words, more than 80% of the individuals are marketed outside its native range. By contrast, in 1977, 19 million elvers arrived to one single lake, Lough Neagh, whereas in 2001 only 945,000 arrived to the same lake (Anonymous 2004)

The effective population size of the European eel is estimated to a mere 5,000–10,000 individuals (Wirth and Bernatchez 2003) or even less than 1,000 (Wickström pers. comm.). The fecundity for the American eel is about two to twenty million eggs where larger females have more eggs, whereas slightly lower figures previously given for the European eel are suggested to have been due to differences in counting techniques and also artifactual effects (Barbin and McCleave 1997).

The European glass eels are typically exported world-wide by air and/or road within the European continent. They have until recently been transported without water in a moist environment in Styrofoam boxes, and then often chilled with ice. In an effort to minimize transport mortality, some glass eel exporters now use specially built containers with dedicated oxygenation. Depending on size of the eels, one box may contain 2,000 to 5,000 glass eels per kg and one shipment contains many boxes. American glass eels (*Anguilla rostrata*) sold in Europe tend to be smaller with 5,000–8,000 per kg. Live adult eels are transported longer distances by air and shorter distances on road in tanker lorries ("tank trucks") and have a much higher market value, and processed eels even higher values per individual.

Mortality rates in the trade estimated for the Japanese eel tend to be lower than for the European eel. Asian industry standards for *A. japonica* require 600–900 kg of marketable eel biomass per kg glass eel (with a 90–95% survival rate) within 9–12 months from the glass eel stage, whereas the European eel yield 110–130 kg and has a lower survival rate of 10–45% (Gooley 1997). The Japanese eel therefore also has the higher market value.

Pond raising of eels, i.e. aquaculture, has a long history in East Asia, more than one hundred years, and the young of the European eels have been exported to Japan at least since 1930s (Matsui 1984). In later decades they have also included export to other countries in that region (Frost 2001, Ringuet *et al.* 2002). Target markets in East Asia of European glass eels include e.g. China, Japan, Korea, and Indonesia.

Table 5. Global production in metric tonnes of freshwater eels, family Anguillidae from 1987 to 2006. Data from FAO – Fisheries and Aquaculture Information and Statistics Service (www.fao.org). The harvest from mariculture, aquaculture and other kinds of fish farming is also included. Please also see Figure 4 and Table 7 for *Anguilla anguilla*.

Species	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
A. japonica	84150	93732	150759	165382	179257	184900	180160	179777	181014	207222	223539	207677	208605	220808	218744	223468	223078	239251	233564	258121
A. anguilla	16510	18938	17131	17969	16619	17424	17123	17650	15693	17199	18830	17058	17826	18699	17706	15166	14490	14263	13286	16613
A. spp	2713	2516	2773	3739	2795	3567	3028	6026	3977	24804	4007	11713	2860	8033	5778	3653	3748	4549	2772	2492
A. rostrata	1288	1736	1791	1713	1872	1682	1649	1798	1322	1316	1270	1244	1125	1338	868	787	1119	840	804	689
A. australis	250	250	250	318	500	497	549	630	459	409	518	475	236	217	284	244	165	126	105	93

Table 6. Global production in metric tonnes of eel-shaped fishes from 1987 to 2006. Data from FAO – Fisheries and Aquaculture Information and Statistics Service (www.fao.org). The harvest from mariculture, aquaculture and other kinds of fish farming is also included.

	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
Clariidae	78759	80199	101708	105965	130686	125573	133240	126759	178033	156638	187418	188940	213435	255302	269318	287204	350257	388931	429100	470137
Muraenesocidae	44335	40749	40891	63413	69017	62125	100087	180130	187888	209150	221618	277537	278150	257173	280156	288751	323789	353459	330397	434647
Anguillidae	104911	117172	172704	189121	201043	208070	202509	205881	202465	250950	248164	238167	230652	249095	243380	243318	242600	259029	250531	278008
Synbranchidae	0	0	0	0	0	0	0	0	1	0	12	16	539	200	138	325	125736	137836	162615	192723
Congridae	36147	37489	41868	41103	42327	44861	51689	44848	54144	51309	51650	43324	39006	35511	34286	45929	47662	45015	40638	45771
Protopteridae	9905	8369	6169	4960	4369	6663	4993	8829	8931	7653	12313	11091	11428	8827	9911	7337	8290	17106	16923	17964
Plotosidae	934	986	915	1456	1338	1088	2133	3399	2633	2644	2210	2860	2380	3533	3133	3189	2201	2219	2368	2788
Myxinidae	0	0	0	0	0	0	478	1105	1398	1959	422	1448	2558	3230	740	1675	1486	1576	1491	909
Muraenidae	0	0	0	0	128	111	166	910	837	710	268	165	335	358	354	359	367	417	370	456
Petromyzontidae	379	337	496	384	103	222	299	189	168	251	140	151	240	244	204	278	275	221	303	228
Ophichthidae	128	189	732	891	1111	491	157	260	165	105	118	39	356	295	270	41	61	188	251	106
Mastacembelidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	71	74	80
Synaphobranchidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	3	1	2	0

Table 7. Production in metric tonnes of European eel as reported by Eurostat (February 2007, http://epp.eurostat.ec.europa.eu; retrieved 18 Oct 2008).

	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
DK	842	701	757	560	681	600	625	696	748	667	1306	1484
SE	973	945	931	533	596	448	462	531	469	462	557	605
NO	454	353	467	341	447	281	304	310	240	237	249	293
DE	34	146	196	167	196	137	139	135	131	123	111	117
ES	176	220	294	240	256	325	310	55	42	68	70	84
FR	82	96	53	44	78	62	52	51	57	53	41	62
RU	33	36	34	25	19	40	53	52	52	58	54	54
PL	237	266	233	231	226	172	162	127	118	82	76	53
NL	40	36	31	22	40	21	34	21	16	31	17	16
EE	6	19	18	22	28	27	27	27	19	16	9	9
PT	3	5	4	6	2	4	7	4	5	2	3	7
UK	52	37	34	11	7	1	12	10	16	7	3	2
LV	2	1	2	2	2	2	2	2	2	3	4	2
IE	0	150	150	250	250	0	0	0	0	0	0	1
LT	–	–	–	–	–	–	–	11	1	0	0	0
FI	0	0	0	0	0	0	0	0	0	0	0	0
Europe	2934	3011	3204	2454	2828	2120	2189	2032	1915	1809	2500	–
EU 27	2447	2622	2703	2088	2362	1799	1832	1669	1623	1514	2197	–
EU 25	2447	2622	2703	2088	2362	1799	1832	1669	1623	1514	2197	–
EU15	2202	2336	2450	1833	2106	1598	1641	1502	1483	1413	2108	–
EEA 30	2901	2975	3170	2429	2809	2080	2136	1980	1863	1751	2446	–
EEA 28	2901	2975	3170	2429	2809	2080	2136	1980	1863	1751	2446	–
EEA 18	2656	2689	2917	2174	2553	1879	1945	1813	1723	1650	2357	–
EFTA	454	353	467	341	447	281	304	310	240	237	249	293

Figure 5. Live glass eels. Depending on species and stage of the glass eel, 1 kg of glass eel may contain 2,000-8,000 individuals. All photos by kind permission of Håkan Wickström.

Figure 6. Eel transport. Larger live eels are often transported by specially built tanker lorries. All photos by kind permission of Håkan Wickström.

The legislation on fish stocking varies greatly both between and within countries in Europe and other parts of the world. Glass eels are stocked deliberately (and accidentally) in natural waters, both in Europe and East Asia, and the young are allowed to grow to adult sizes without further human meddling.

Recently, Chang *et al*. (2008) reported on a large specimen of *Anguilla reinhardti* measuring 175 cm and weighing 18 kg captured near Taipei, far from its native range in eastern Australia. They believed it had been released for religious belief, or escaped from an aquarium or restaurant. Lin *et al*. (2002) noted that most of the marbled coloured specimens in the fish market often are *A. reinhardti* imported from Australia, but sold as *A. marmorata*, a native, protected species. The two species, *A. reinhardti* and *A. marmorata*, are very similar and unsuspecting customers probably never notice the differences if only one of the species is marketed.

The European eel is known to occur in Japanese rivers since the late 1970s and both the American eel (Frankowski *et al*. 2008) and the Japanese eel (Kirk 2003) have been found in European natural waters and/or aquaculture but it is not likely that transplanted eels may hybridize with the native species or establish reproducing populations. Dekker (2003) noted that ICES (2000) "focusing on the protection of the spawning stock, advocated against restocking as a stock-rebuilding measure" and Westin (2003) concluded that the

restocking of the European eel, even if within its natural distribution: "brings no long-term benefit to the natural eel population, since it makes no contribution to natural recruitment" and "transplanted individuals do not participate in spawning, and thus that the transplantations will not have affected the natural genetic structure of the European eel population". The reason seems to be the lack of migration cues in transplanted eels. ICES (2008a) reiterated: "there is a continuing and urgent requirement for robust evidence of the extent to which stocking and transfers on local, national and international scales can increase silver eel escapement and spawner biomass" and advised (2008b) that "large-scale stocking should not be allowed unless a scientific evaluation demonstrates that the potential escapement of silver eels will be enhanced."

It is difficult to identify the fifteen eel species known. This is perhaps reflected in the catch statistics reported by FAO where "*Anguilla* spp." is the third largest group of *Anguilla* production reported (Table 5). There are also reports on deliberate mislabeling of fish species (e.g. Rasmussen and Morrissey 2008, Schwartz 2008) and the eel trade is no exception. Lin *et al*. (2002) noted that eel mongers tend to mix more expensive species with less desirable species. It is therefore important to be able to identify the eel species in order to follow up on various protection measures and to enforce trade bans and other restrictions. It is notable that both A. *marmorata* and *A. bicolor* are missing from the statistics as both are highly traded in Asia (Talwar and Jinghran 1991, Williamson and Boëtius 1993, Grey *et al*. 2006, Modayil *et al*. 2008).

The eel parasite *Anguillicola crassus* originally infected the Japanese eel (*Anguilla japonica*), but is reported from European eel since an introduction due to a live eel import from East Asia in the early 1980s. The parasite is now reported from all over Europe, North Africa and eastern United States (Kirk 2003). Hayward *et al*. (2001) demonstrated using molecular methods that another eel parasite, with a world-wide distribution today, *Gyrodactylus anguillae*, probably originates from Europe but has spread around the world also in a comparatively short time period. These two cases of rapid spread are also indirect indications of the magnitude and swiftness of the world eel trade which is carried out using both road and air transport.

Some countries have already introduced a ban on catch and export of glass eels, e.g. Indonesia (Tjakrawidjaja 2001) and Hawaii has not allowed import of eel since 1974 (James and Suzumoto 2006). It is not legal in New Zealand to catch or export glass eels, or, catch any eel below the minum commercial size of 220 g (Jellyman 2007). The length of the endemic New Zealand eel *Anguilla dieffenbachi* at 220 g typically is about 500 mm TL, as estimated from data provided by Chisnall (2000). Unfortunately there is no comprehensive overview of legislations for the world.

In recent years, the prices for eel-fry have sky-rocketed and while it is a very lucrative market there are several reports on large-scale illegal trade. In 2006 (Anonymous 2006), 2007 (Gainey 2007), and 2008 (e.g. Poyser 2008, Gainey 2008, Evans 2008), British officers have caught and fined several persons for illegally fishing young eels. At the Narita Airport alone, Japanese authorities have in 2006 blocked 24 attempts to export a combined 2.4 metric

tonnes of eel fry and in 2007 the Japanese Coast Guard arrested 10 people for trying to smuggle 143 kg of eel fry to another country in East Asia (Anonymous 2007). Sage (2007) reported on two French brothers which were arrested and convicted of catching more than 300 kg elvers in Bordeaux, and while there are 200 licenced French eel fishermen according to a French gendarmerie spokesman: "There are up to 200 poachers working in gangs and most are well organised with spotters to say when we are coming." During 2008, Swedish authorities have been notified of numerous illegal eel traps concealed in smaller streams along the Atlantic Coast of Sweden (Strid 2008a, 2008b).

The adult eel trade outside Europe is extensive and is prominent in North America, Asia, as well as Africa. For example, Macintosh *et al.* (2002) described a small scale fishery in western Thailand near the border of Myanmar (Burma) where one fisherman catch 20–100 kg live eel in one day. The eels are transported live by a middleman to Bangkok, where the fish are later exported to China, Hong Kong and elsewhere.

The Internet has become a fast and easy way for small scale exporters and importers to meet. One of these meeting places is a websites called "Alibaba" at www.alibaba.com. They are among the most visited web sites (with an Alexa ranking of 16714, www.alexa.com) and describe themselves as "the world's largest marketplace for global trade and the leading provider of online marketing services for importers and exporters. It is the place for buyers and sellers to find trade opportunities and promote their businesses online". A cursory examination (19 Oct 2008) of only the freshwater eel offerings reveals that frozen glass eels are exported from Madagascar (*A. mossambica* and *A. marmorata*), adult frozen eels from e.g. Indonesia (*A. bicolor*) and Canada (*A. rostrata*), live "big eel" from Tahiti (*A. marmorata*, *A. megastoma*, *A. obscura*), and many more examples. A brief overview of the trade at that site is presented in Table 8 and may give a glimpse of the relative proportions and scale of the international freshwater eel trade. The numbers within parentheses give the number of contacts available for each category.

China is the largest eel producer for the Japanese market and has also been the main importer of European eels during the last decade. However, the Chinese eel export has repeatedly had setbacks (Frost 2001) and recently the United States Food and Drug Administration (FDA) wrote (www.fda.gov/consumer/updates/ fishtimeline062807.html): "*Nov. 13, 2006 Import alert for eel from China due to presence of malachite green residues.*" and "*On June 28, 2007, FDA announced a broader import control of all farm-raised catfish, basa, shrimp, dace (related to carp), and eel from China until the shipments are proven to be free of contaminants.*"

While the freshwater eel fishery around the world is large, about 250,000 tonnes, it is dwarfed by the fishery for other groups of fish. For example, the fishery for cod and relatives, Gadiformes, is about 5–10 million metric tonnes per year and the fishing for herring and anchovies, Clupeiformes, is about 15–25 million tonnes per year. The total production of fish in the world is about 140 million tonnes per year (FAO 2006).

Labelling

The Codex Alimentarius Commission implements the Joint FAO/WHO Food Standards Programme, the purpose of which is to protect the health of consumers and to ensure fair practices in the food trade. The Codex Alimentarius is a collection of internationally adopted food standards and includes codes of practice, guidelines and other recommended measures to assist in achieving the purposes of the Codex Alimentarius. The Commission has expressed the view that codes of practice might provide useful checklists of requirements for national food control or enforcement authorities. The publication of the Codex Alimentarius is intended to guide and promote the elaboration and establishment of definitions and requirements for foods to assist in their harmonization and, in doing so, to facilitate international trade. The Codex Alimentarius can be accessed at www.codexalimentarius.net.

According to FAO (ftp://ftp.fao.org/codex/Publications/Booklets/Labelling/foodlabelling_2005e.pdf; retrieved November 2008), there are a number of foods and ingredients that are known to cause hypersensitivity in humans and shall always be declared. Among that list are fish and fish products, which must be labelled at least with the general class name ”Fish” which means ”all species of fish where and when the fish constitutes an ingredient of another food and provided that the labelling and presentation of such food does not refer to a specific species of fish”. There is, in other words, currently no requirement to label, e.g. prepackaged food with species specific contents. The term “prepackaged” means packaged or made up in advance in a container, ready for offer to the consumer, or for catering purposes.

Examples of prepackaged forms of European Eel would include frozen eel (univiscerated or eviscerated), smoked eel, marinated eel (in e.g. oil or vinegar), etc. These terms also have many culinaric names in different European languages but there is no complete overview for all languages which would identify all food products which would contain European eel. For example, the Japanese dish ”unagi kabayaki” is known to often be based on the European eel rather than the Japanese eel. The name list given below, at the species account does, however, list many of the more common names used in the trade.

The Codex Alimentarius does provide a classification of foods and animal feeds, that includes some freshwater eels; they all belong to Class B (Aquatic animal products Group 041) and have the code numbers WD4897 (American eel, *Anguilla rostrata*), WD4899 (Australian eels, *A. australis* and *A. reinhardti*), WD4901 (European eel, *A. anguilla*), and WD4903 (Japanese eel, *A. japonica*). WD0890 Eels (*Anguilla anguilla ; A. japonica; A. rostrata; A. australis*; and *A. reinhardti*).

The detection of and positive species identification of the European eel in prepackaged and/or processed food is possible, through several alternative techniques discussed in detail below.

Table 8. An overview of the international trade of various eel product by select categories. Data retrieved from the business-to-business Internet contact network www.alibaba.com. Numbers within parentheses indicate the number of interested business partners. (continued on next page)

Smoked eel	
Sellers	**Buyers**
Taipei (5)	N America (6)
China (mainland) (3)	E Asia (6)
Canada (1)	Oceania (6)
Guatemala (1)	S America (5)
	E Europe (5)
	SE Asia (5)
	Mid East (5)
	Africa (5)
	W Europe (2)

Kabayaki	
Sellers	**Buyers**
China (mainland) (12)	N America (12)
	E Europe (12)
	E Asia (12)
	Mid East (12)
	S America (10)
	SE Asia (10)
	Africa (10)
	Oceania (10)
	W Europe (3)

Roasted eel	
Sellers	**Buyers**
China (mainland) (23)	N America (25)
United States (5)	E Asia (25)
Hong Kong (1)	E Europe (24)
Taipei (1)	Mid East (23)
	S America (21)
	SE Asia (20)
	Africa (20)
	Oceania (20)
	W Europe (7)

Frozen eel	
Sellers	**Buyers**
China (mainland) (29)	E Asia (70)
Indonesia (12)	SE Asia (69)
Pakistan (12)	Mid East (68)
Bangladesh (6)	N America (62)
India (5)	E Europe (55)
Taipei (5)	Africa (51)
Vietnam (5)	Oceania (49)
Canada (3)	S America (48)
United States (3)	W Europe (36)
Chile (2)	
Hong Kong (2)	
Madagascar (2)	
Malaysia (2)	
Philippines (2)	
Turkey (2)	
United Kingdom (2)	
France (1)	
Guatemala (1)	
Peru (1)	
Singapore (1)	

Table 8 (continued from previous page). An overview of the international trade of various eel product by categories. Data retrieved from the business-to-business Internet contact network www.alibaba.com. Numbers within parentheses indicate the number of interested business partners. (continued on next page)

Glass eel	
Sellers	**Buyers**
Philippines (6)	SE Asia (10)
Madagascar (5)	W Europe (5)
Australia (1)	N America (4)
Spain (1)	E Asia (4)
	S America (1)
	E Europe (1)
	Mid East (1)
	Africa (1)
	Oceania (1)

European eel	
Sellers	**Buyers**
China (mainland) (5)	E Europe (8)
Estonia (1)	N America (7)
Russian Federation (1)	S America (7)
Spain (1)	E Asia (7)
	SE Asia (7)
	Mid East (7)
	Oceania (7)
	W Europe (5)
	Africa (4)

Live eel	
Sellers	**Buyers**
Bangladesh (22)	SE Asia (54)
Indonesia (18)	N America (43)
United States (10)	E Asia (42)
China (mainland) (6)	Mid East (37)
Madagascar (5)	S America (36)
Canada (4)	E Europe (35)
Hong Kong (4)	Oceania (35)
Philippines (4)	W Europe (34)
Taipei (4)	Africa (32)
Australia (2)	
French Polynesia (1)	
Malaysia (1)	
Myanmar (1)	
Spain (1)	

Japanese eel	
Sellers	**Buyers**
Chile (1)	SE Asia (3)
Hong Kong (1)	N America (2)
Philippines (1)	S America (2)
	W Europe (2)
	E Europe (2)
	E Asia (2)
	Mid East (2)
	Africa (2)
	Oceania (2)

American eel
No matches were found in Products for: American eel

Big eel	
Sellers	**Buyers**
Indonesia (4)	E Asia (5)
Bangladesh (1)	Oceania (4)
China (mainland) (1)	N America (3)
French Polynesia (1)	S America (3)
	W Europe (3)
	E Europe (3)
	SE Asia (3)
	Mid East (3)
	Africa (3)

Atlantic eel	
Sellers	**Buyers**
Canada (2)	N America (2)
	S America (2)
	W Europe (2)
	E Europe (2)
	E Asia (2)
	SE Asia (2)
	Mid East (2)
	Africa (2)
	Oceania (2)

Figure 7. Example of canned eel offering from East Asia, which may or may not contain European eel. Matchbox included for comparison purpose. All photos by kind permission of Håkan Wickström.

Figure 8. Prepackaged "false angulas" which imitate true glass eels but are made of other fish species. Photo by kind permission of Anders Asp.

Figure 9. Prepackaged glass eels, known as "Angulas", a delicacy found in several parts of Europe. Photo by Håkan Wickström (upper) and Anders Silfvergrip (lower).

Artificial breeding

Since a few years, artificial breeding of freshwater eels is a reality, at least for the Japanese eel which have been "obtained under completely artificial conditions" (National Research Institute of Aquaculture; http://nria.fra.affrc.go.jp/biology/biology-e.html, retrieved 17 Oct 2008 [web page first published 10 August 2007, according to www.archive.org]). The artificial breeding of the European eel is less successful but a Danish research team has still managed to produce free-swimming self-feeding larvae up to 18 days old (Wickström, pers. comm.).

Yamamoto and Yamauchi (1974) were the first to successfully obtain fertilized eggs and larvae of the Japanese eel, using hormone treatments. Since then, artificially raised eels have been shown to have both different meristics and body proportions from wild caught material (Mochioka 1996, Tanaka *et al*. 2001). That and the recent production of artificial hybrids (Okamura *et al*. 2004) between *Anguilla japonica* and *A. anguilla* may cause concern about the future prospects of the identification of eel species using either morphological or molecular techniques based on the mitochondrial genome.

Freshwater eels – Anguillidae

The family Anguillidae belongs to the order Anguilliformes, true eels, a large monophyletic group of eel-shaped bony fishes (Obermiller and Pfeiler 2003, Inoue *et al*. 2004, Lopez *et al*. 2007) with more than 750 species (FishBase 2008). The order (including the former Saccopharyngiformes, Inoue *et al*. 2004) contains nineteen families (Inoue *et al*. 2004, Lopez *et al*. 2007), of which the Anguillidae (freshwater eels), Congridae (conger eels), Muraenesocidae (pike-congers), Muraenidae (moray eels), Ophichthidae (snake-eels), Synaphobranchidae (cutthroat eels) all are found in the international trade. Other groups of anguilliform species may have trade locally but are not expected to appear in large quantities in international trade. The Anguilliformes belongs to a more inclusive group of fish called Elopomorpha, which also includes e.g. ladyfish, bonefish, and tarpon (Greenwood *et al*. 1966, Inoue *et al*. 2004).

The freshwater eels (Anguillidae, *Anguilla* spp.) can be recognized from all other eel-shaped fish commonly found in the commercial fish trade by a unique set of characters. Eyes well developed. Posterior nostril in front of eye. Jaws well developed, with the lower jaw invariably the longer. All fins without hard spines. One dorsal fin, long, low, and remote from head. Anal fin long, low, to just behind anus. Caudal fin confluent with both dorsal and anal fins. Pectoral fins well developed. Pelvic fins invariably absent. Barbels invariably absent (not to be confused with short tubular nostrils). Anus located just in advance of midbody. Gill openings paired, well separated left and right side openings as small vertical slits at pectoral fin base. Scales invariably present, but often hard to detect.

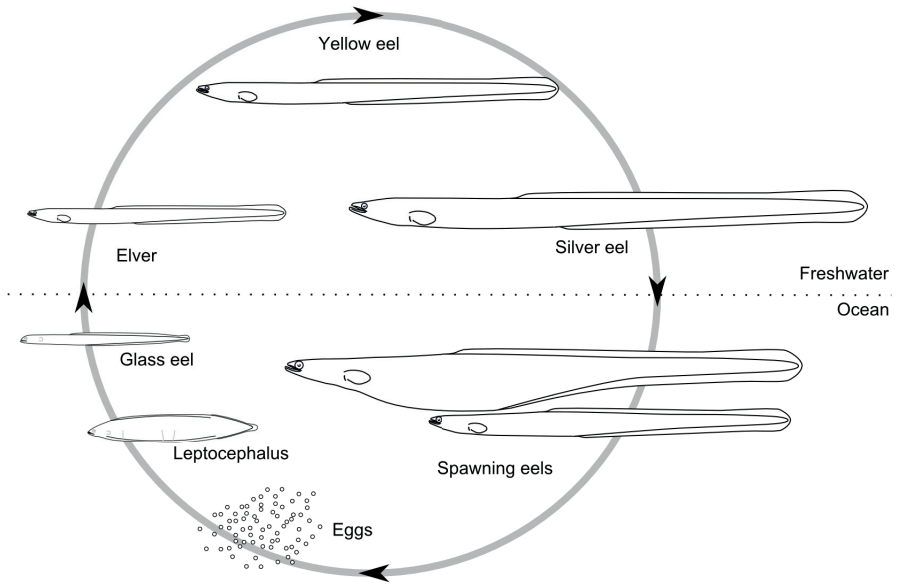


Figure 10. Generalized catadromous life-cycle found in all freshwater eels. It has recently been discovered that not all individuals enter freshwater but rather complete their life-cycle entirely in a marine environment. The freshwater phase may last from ve to thirty years whereas the oceanic phase typically is two or three years.

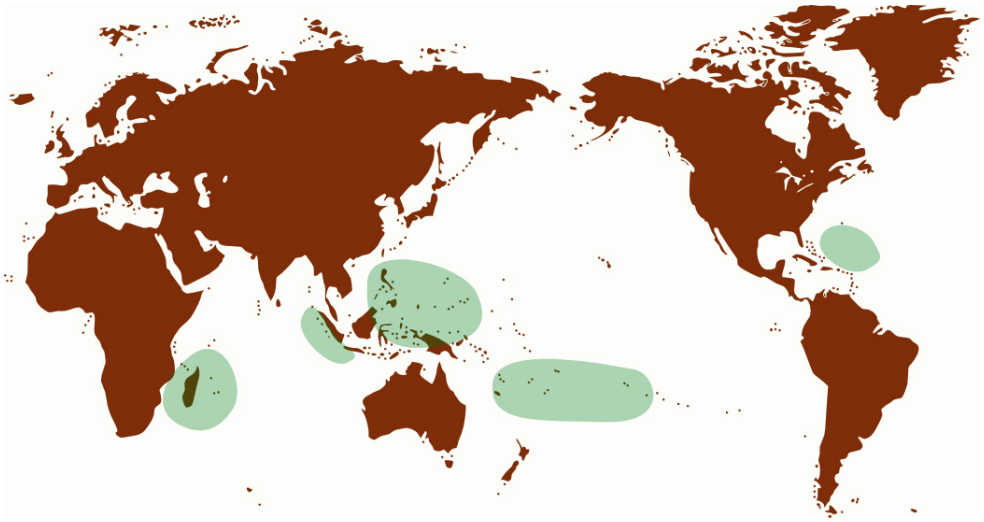


Figure 11. The ve main larval areas of the freshwater eels as suggested by Jespersen (1942). More recent studies have largely con rmed the pattern and in more detail.

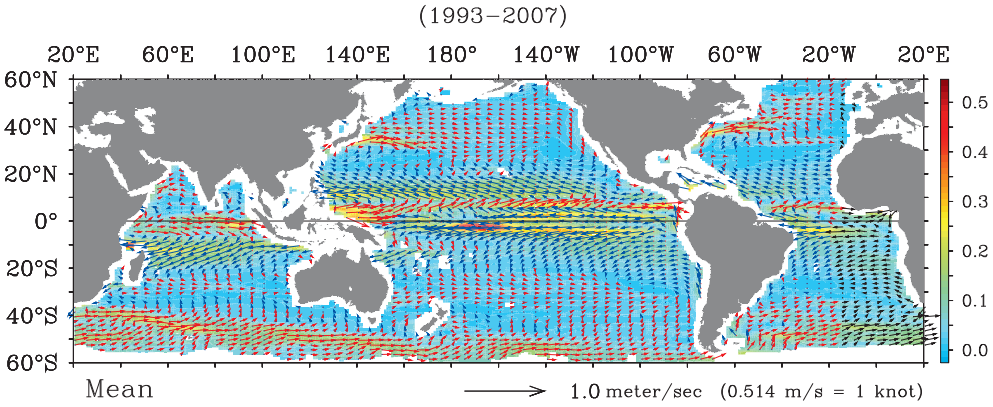


Figure 12. Mean sea surface currents during 1993–2007. Map from NESDIS/NOAA (www.oscar.noaa.gov/).

The freshwater eels are the textbook examples of catadromous fishes that spend most of their lifetime in freshwater and after many years return to the sea for a single spawn and an ultimate death. Recent studies have shown that at least some species may be considered facultative catadromous fishes, i.e. not all eels migrate to fresh water during their lifetime, but some stay in the sea along the seashore without ascending the rivers (Tsukamoto *et al.* 1998, Tsukamoto and Arai 2001, Daverat *et al.* 2006, Thibault *et al.* 2007). They occur in all tropical and temperate oceans, except along the western coast of the Americas and in the south Atlantic.

The exact spawning areas are not known for most species and the areas have been determined by the combination of several indirect measures, e.g. leptocephalus larval sizes (Schmidt 1922, discovering the Sargasso Sea as the larval nursery for both the American and European eel), otolith growth rings, Sr/Ca ratios, sea currents, etc.

Jespersen (1942) suggested there are five main regions for freshwater eel spawning in the world: (1) Western Atlantic Ocean, (2) Western Indian Ocean, (3) Eastern Indian Ocean, (4) Western Pacific Ocean, and (5) Southern Pacific Ocean (Figure 11). One species may use several of these areas for spawning. For comparison, the world sea surface currents based on OSCAR data (Bonjean and Lagerloef 2002, Johnson *et al*. 2005) are presented in Figure 12.

The spawning seasons vary between species as well their larval drifting distances. Aoyama *et al*. (2003) suggested that *A. borneensis*, endemic to streams in eastern Borneo, spawns in the Celebes Sea less than 1,000 km away. This can be contrasted with *Anguilla anguilla* entering the River Nile in Egypt, whose larvae then have travelled ten times that distance. The life cycle of freshwater eels has been described as a 'migration loop' and believed to have originated with only a short distance migration (Tsukamoto and Aoyama 1998, Tsukamoto *et al*. 2002, Aoyama *et al*. 2003).

Using oceanographic data and glass eel catch series, Bonhomme *et al*. (2008a, 2008b) suggested that the covariation in the eel nursery sea temperatures and eel recruitment in Europe, America and Japan "may have led to the decline of European, American and Japanese eel populations". However, both studies fail to address the 5.8 million year old split (Minegishi *et al*. 2005) between *A. anguilla* and *A. rostrata* which shows that both species have endured several climatic changes for the last 6 million years (e.g. Zachos *et al*. 2001, Lunt *et al*. 2008a, 2008b). Kettle *et al*. (2008) discussed past distributions of the European eel, but based their conclusions on older molecular studies not as comprehensive as Minegishi *et al*. (2005) which is based on the entire mitochondrial genome.

Leptocephalus larvae

The leptocephalus larva is the first life stage after hatching in all elopomorph fish and the larva has radically different morphology from the adults. Richards (1984) and Castle (1984) have illustrated the leptocephalus larvae for various elopomorph families and Fahay (2007) presented a comprehensive overview of the early stages of the western North Atlantic fishes (a pdf-version is available for free download at www.nafo.int/Publications/frames/fahay.html). The size of most of the larvae range from 10 to 90 mm total length (TL) and Miller and Tsukamoto (2006) discuss techniques for the identification and preservation of leptocephalus larvae.

The leptocephalus larvae are transparent and have two stages, the engyodontic and the euryodontic stages (Castle 1984). The transparency comes in part from that the red blood cells do not develop until the transformation from leptocephalus stage to the glass eel stage. The engyodontic life stage is the first life stage from the hatching of the egg to the resorption of the yolk sac at about 20 mm TL. The body shape is eel-like elongated with a near round cross-section. The euryodontic stage, the second life stage of the leptocephalus larva, starts at about 20 mm TL. The larva become markedly flattened from the sides, with the body depth more than five times its width.

Miller and McCleave (1994) studied the leptocephalus larvae of the Subtropical Convergence Zone of the Sargasso Sea, where larvae of more than 100 anguilliform species occur. In that particular study, they found about fifty species of leptocephalus larvae of which only ten species were common. All samples were fixed in 7.5% seawater-formalin before the leptocephali were sorted and identified under a binocular stereoscope. While there are only two *Anguilla* species in the area (*A. anguilla* and *A. rostrata*), they could demonstrate that the larvae of the two species had different geographic distributions, with *A. anguilla* being more common from trawling transects to the east.

Miller *et al* (2006) performed a similar study in the western South Pacific, an area with several *Anguilla* species. They noted: "Some of these anguillid leptocephali were subsequently identified genetically [Aoyama *et al*. 1999], but the species identification of the remaining anguillid specimens preserved in formalin was not possible using morphological analysis due to their small size and because their meristic characters such as total number of myomeres have overlapping ranges among different species". Aoyama *et al*. (2003) examined leptocephalus larvae from the waters around Celebes and using molecular techniques, they identified freshwater eel larvae as small as 8.5 mm TL. Using that technique, also eggs can be identified.

Strehlow (1996) examined 387 premetamorphic freshwater eel leptocephali from of the west coast of Europe and the Sargasso Sea. The total number of myomeres and the number of myomeres up to the third, opistonephritic blood vessel in *Anguilla anguilla* are significantly different from those of the larvae of *A. rostrata* and do not change during the whole larval phase. According to Strehlow (1996), the combination of these two features allows "infallible" species identification of the Atlantic *Anguilla* larvae, at all developmental stages. In contrast, Aoyama *et al*. (1999) found that many misidentifications may occur, using morphological identification, and later stated (Aoyama *et al*. 2007): "to identify the leptocephali of the tropical anguillid species, genetic methods are required", which then also applies on a global scale.

Some countries do not allow fishing for eels smaller than 50 mm TL, e.g. Indonesia (Tjakrawidjaja 2001), which then include both leptocephalus larvae and smaller glass eels. The leptocephalus larvae of the Japanese conger (*Conger myriaster*) are caught commercially, however, and are served and eaten live when they are about 50–60 mm total length. The dish has different names in different parts of Japan, e.g. *noresore*, *berada*, *tachikurage*, or *nagatankurage* and are a spring seasonal specialty for a few weeks.

Glass eels

After hatching, the freshwater eel leptocephalus larvae drift with the ocean currents a shorter or longer distance, depending on species. The European eel leptocephalus larvae have the longest distance to travel and it consequently has among the largest larvae. The growth is synchronized so that its metamorphosis from the ribbon-like larvae into the cylindrical glass eel occurs just before they reach the target coastal waters.

Bast and Strehlow (1990) noted that large samples of glass eels from Gibraltar to the North Sea had means ranging from 65.6 to 78.4 mm TL. The first glass eels to arrive in the year are typically larger and completely transparent whereas later arrivals are smaller and already pigmenting. Tropical species, which do not drift as far, tend to have much smaller larvae rarely exceeding 60 mm TL, and often smaller than 50 mm TL (Jespersen 1942, Marui *et al*. 2001, Arai *et al*. 2001b, Aoyama *et al*. 2003, Robinet *et al*. 2003, Kuroki *et al*. 2006). Thus, single species samples with a large proportion of glass eels smaller than 55 mm TL probably is not *Anguilla anguilla*, while it also could be an indication of a mixed species sample.

The recruitment period of the elvers varies between species and appear seasonally adjusted for the *Anguilla* species from temperate regions whereas the tropical species appear to recruit year round (Arai *et al*. 2001b, Sugeha *et al*. 2001). In addition, the inshore migration is also very variable with some species favoring night time and synchronized with the moon phases whereas others uses both day and night (Sugeha *et al*. 2001).

The caudal fin of glass eels may have species specific pigmentation patterns, which often can be used for species identification at a local or regional level. For example, Tabeta (1988) and Lee *et al*. (1997) noted for *A. japonica* and *A. marmorata*: "Morphologically, elvers of these two species can be distinguished by the more numerous myomeres or vertebrae in *A. japonica* (112–119) than in *A. marmorata* (102–108), and the latter having a slightly darkened tail tip". Illustrations and photographs of caudal fin patterns have been published by e.g. Ege (1939), Lecomte-Finiger *et al*. (2000), and Robinet *et al*. (2003). Such data is unfortunately not available for all species, or their different populations, or for specified glass eel stages. The ontogenetic variation in *Anguilla anguilla* was in part described by e.g. Jegstrup and Rosenkilde (2003). While the caudal fin pattern is important in the identification of glass eels, it is not further considered here, but suggested as future work on a global level.

Adults

After entering the rivers, the glass eels rapidly develop pigmentation and become "yellow eels", which stay in freshwater for growth for many years before they become mature as "silver eels" and migrate back to the sea. During maturation they develop a typical silvery color and much larger eyes.

There are alternative classifications of the various stages of the adult eels. These typically predict at which stage the eels start to migrate and what factors regulate maturation, etc. There is also variation between species. For example, *Anguilla australis* needs to reach a minimum size and age before they start to migrate, even if the exact size and age varies between populations (De Silva *et al*. 2002). In *A. anguilla* there is no threshold size or age before they start to migrate and what triggers maturation is not known (Svedäng *et al*. 1996).

Taxonomy

The taxonomic history of eels is long and complicated and includes many synonyms which are listed below for each species. The list of nominal species and synonyms follows Eschmeyer's (1998) 'Catalog of Fishes' as well as the on-line version at www.calacademy.org (updated 29 August 2008), FishBase (version 7/2008, www.fishbase.se, retrieved September 2008), and other sources.

There are currently fifteen species in one genus, *Anguilla*, in the family Anguillidae, according to studies by Aoyama *et al*. (2001), Lin *et al*. (2001, 2005), Minegishi (2005), and Watanabe (2006): *Anguilla anguilla*, *A. australis*, *A. bengalensis*, *A. bicolor*, *A. celebesensis*, *A. dieffenbachi*, *A. interioris*, *A. japonica*, *A. borneensis*, *A. marmorata*, *A. megastoma*, *A. mossambica*, *A. obscura*, *A. reinhardti*, and *A. rostrata*. The classification stems from Ege (1939) who examined the morphology of about 25,000 specimens from all over the world. Ege (1939) recognized sixteen species but Castle and Williams (1974) concluded that a species described by Ege was in fact elvers (45–54 mm) of *Anguilla celebesensis*.

The validity of some species have been questioned recently and Aoyama *et al*. (2000) concluded that *A. celebesensis* and *A. interioris* cannot be diagnosed using morphology but require molecular data, even if they called for larger sampling efforts of both species to substantiate the molecular difference they found comparing two small samples. However, in Minegishi *et al*. (2005), *A. interioris* is grouped together with other species and the situation remains uncertain.

The question of how many species there are in *Anguilla* is, however, subordinate which species concept is followed. Queiroz (1998) listed numerous species concepts, of which, however, only a few are in current use. The use of subspecies has had little support in the scientific community during the last decades and subspecies are not used here. There is a difference in tradition between authors mainly using morphology and/or molecular data, with the former often favoring *diagnosis* and the latter *reciprocal monophyly* (see discussions in e.g. Cracraft 1983, Avise 2000, Avise and Walker 2000, and Funk and Omland 2003). The number of species in the Anguillidae and their geographic distributions may change depending on the choice of species concept.

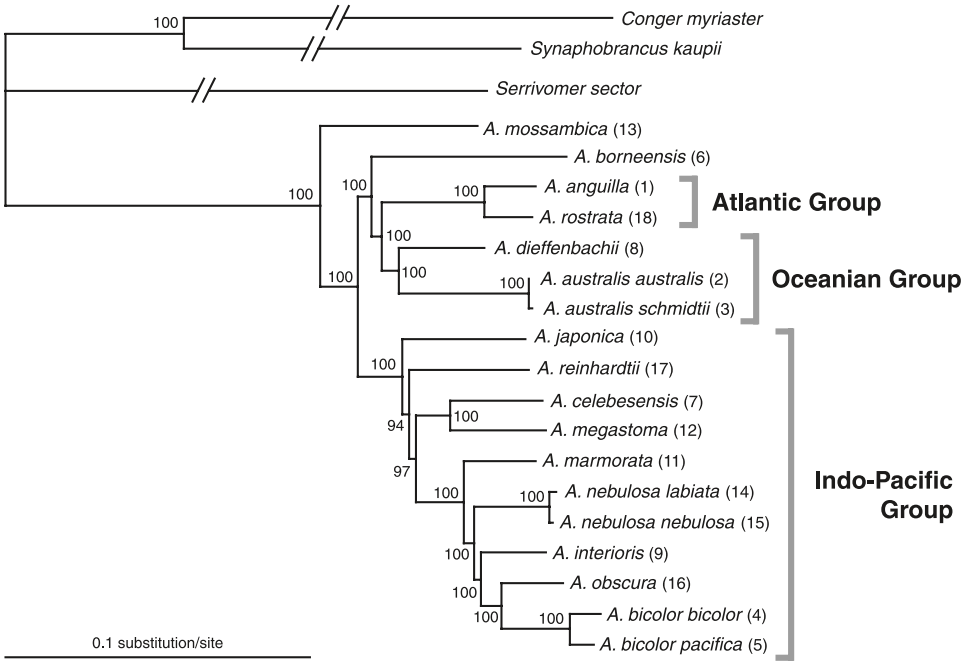


Figure 13. Relationships of the Anguillidae according to Minegishi *et al*. (2005) based on the complete mitochondrial genome. Numerals at internal branches are Bayesian posterior probabilities. Numbers within parentheses are terminal taxon number.

Systematics

The interrelationships of the anguillid species have been the focus of numerous recent molecular studies (e.g. Aoyama and Tsukamoto 1997, Lehmann *et al*. 2000, Bastrop *et al*. 2000, Aoyama *et al*. 2001, Lin *et al*. 2001, Lin *et al*. 2005, Minegishi *et al*. 2005, Watanabe *et al*. 2005, Jamandre *et al*. 2007). Figure 13 illustrates the relationships between all *Anguilla* species based on the entire mitochondrial DNA sequence, 15,187 nucleotide positions (Minegishi *et al*. 2005).

There are several molecular studies describing the intraspecific variation of *Anguilla anguilla*. Lehmann *et al*. (2000) published a dendrogram showing that both *A. rostrata* and *A. anguilla* are reciprocally monophyletic using RAPD-PCR. However, Herzberg *et al*. (2002) argued that one may arrive at conflicting results using RAPD-PCR and that: "The reproducibility of RAPD-PCR was shown to be low and the information obtained by this method was clearly not as precise as that obtained from sequence analysis". Dannewitz *et al*. (2005) have demonstrated panmixis of *A. anguilla* by comparing cohort variation and geographical variation and Maes *et al*. (2006) suggested an isolation by time pattern due to two factors, the larger time scale migration loop effects and the smaller time scale reproductive success within cohorts.

Other studies of intraspecific variation in freshwater eels have examined *A. australis* (Smith *et al.* 2001, no evidence of genetic structuring within New Zealand), *A. bicolor* (Watanabe *et al.* 2006, no genetic structuring within the Indian Ocean; Watanabe *et al.* 2005, difference between Indian Ocean and Indo-Malayan archipelago), *A. dieffenbachi* (Smith *et al.* 2001, no evidence of genetic structuring within New Zealand), *A. japonica* (Ishikawa *et al.* 2001, "no evidence for genetic subdivision of *A. japonica*."), and *A. marmorata* (Ishikawa *et al.* 2004 and Minegishi *et al.* 2008, demonstrate the existence of multiple reciprocally monophyletic populations), *A. rostrata* (Avise *et al.* 1986, "no evidence of mtDNA divergence").

Identification

While phylogenetic studies produce sequences that can be used for identification, the studies typically use few specimens and focus on taxonomic breadth whereas studies focussing on intraspecific variation tend to use more specimens from one species (Funk and Omland 2003) and therefore either may not work as a test of diagnosability on their own (Meyer and Paulay 2005). However, molecular identifications presented in this paper support the current taxonomy and as e.g. Watanabe (2005) has pointed out: "Despite minor changes in the taxonomy of the freshwater eels, Ege's (1939) systematics have long been widely accepted by many biologists."

Some molecular studies have successfully targeted identification specifically, e.g. Huang *et al.* (2001, nine species examined, including *A. anguilla*), Lin *et al.* (2002, all species examined), and Tseng *et al.* (2001, seven species examined, but not *A. anguilla*).

Zhang *et al.* (1999) identified 1,048 eel individuals, collected in the natural waters of middle and western Japan from August 1997 to February 1998 using the mtDNA cytochrome b region. They found that both *Anguilla japonica* and *A. anguilla* were present in high numbers.

Trautner (2006) successfully diagnosed *A. anguilla* from *A. rostrata* using PCR amplicon length differences which also is a fast method. However, for ensured reliability their method not only requires the ready availability of a positive control for *A. anguilla* (i.e. fresh tissue of authenticated *A. anguilla* in the laboratory) it also requires new primers for other species that have not been tested versus *A. anguilla*. The method may therefore be of limited use in situations where the origin is unknown. Nieddu *et al.* (1998) and Pichiri *et al.* (2006) have reported on a successful differentiation between *A. anguilla* and *A. rostrata* using filter hybridization using 5S rDNA as a probe.

There may be significant morphological differences between groups of individuals which are not reflected in sequence data and cannot be easily dismissed as ecophenotypical variation. Watanabe (2006) examined the morphological distinction of the New Zealand populations versus the Australian populations of *Anguilla australis*. Dijkstra & Jellyman (1999) and Watanabe *et al.* (2001) had previously compared these two populations and not found

any significant differences in the fast-evolving D-loop. Aoyama *et al*. (2000) found no difference examining 16S rRNA whereas later, and using a larger sample, Watanabe *et al*. (2005) reported that the genetic variation was the largest among the 15 species of the genus *Anguilla* analysed by PCR-RFLP analysis. Watanabe (2006) concluded that there are numerous significant morphometric differences, even if not diagnostic and recommended that future analyses also examine nuclear DNA, which may more directly reflect the observed morphological differences. Shen and Tzeng (2007) reported on the microsatellite variation between *A. australis* samples from Australia and New Zealand their results are described below.

Allozymes

The European eel and the American eel are each others closest relatives (e.g. Aoyama and Tsukamoto 1997, Lehmann *et al*. 2000, Bastrop *et al*. 2000, Aoyama *et al*. 2001, Lin *et al*. 2001, Lin *et al*. 2005, Minegishi *et al*. 2005). Therefore, one may suspect they also share more derived similarities than either does with any other freshwater eel species. Mank and Avise (2003) noted: "Allelic frequency histograms for the two species overlap extensively. Thus no fixed allelic differences were observed between *A. anguilla* and *A. rostrata*, and indeed, private alleles (those present in only one species, in this case) invariably were rare in the available samples." Lee *et al*. (1997) described how to identify *A. marmorata* from *A. japonica* using allozyme electrophoresis.

Protein electrophoresis

Hubalkova *et al*. (2007) listed several protein based methods for fish identification and protein electrophoresis is a well-established procedure for controlling authenticity. IEF (isoelectric focusing) is the current regulatory method for fish identification of the US Food and Drug Adminitration (FDA). Mackie (2000) found that the electrophoresis profiles of three species of eels were unaffected by smoking. *Anguilla anguilla* and *A. rostrata* were indistinguishable using the SDS-PAGE or IEF of water-soluble proteins procedures, whereas a weak difference was found using Urea-IEF. *Anguilla australis* could be identified from either of those two species using any of these three methods, raw or smoked. Comparini and Schoth (1982) examined a large material of leptocephalus larvae from the Sargasso Sea and successfully identifed them using electrophoretic patterns of the MDH-2 locus.

Microsatellites

Liang *et al*. (2005) compared the microsatellite variation between *A. japonica* and *A. anguilla*. They presented a pairwise matrix of FST and RST which showed "significant difference" between the two species. However, their samples were small and differences within their *A. japonica* material was sometimes as high versus their *A. anguilla* material. Shen and Tzeng (2007) reported on microsatellite variation between *A. australis* samples from

Australia and New Zealand: "microsatellite variability in the present study revealed significant differences between populations in Australia and New Zealand to a smaller extent between samples within these regions". They recognized that microsatellite differences can arise on short time scales and also cautioned that "the 20% misassignment of individuals to sample location may indicate that the two regional groups share a common spawning area, but are separated by imperfect homing behaviour".

Later, Maes *et al*. (2006) successfully identified four *Anguilla* species using microsatellites, *A. anguilla*, *A. rostrata*, *A. japonica*, and *A. marmorata*. They noted that microsatellites is useful in forensic analyses as product sizes are small and may also, due to the biparental origins also identify hybrids. However, due to the shortness of the alleles they may also backmutate to former states not acquired through descent thereby limiting their usefulness in phylogenetic analyses. While a strong and important method, it still needs to be performed on the remaining 11 species in order to see how well it performs there.

Real-Time PCR

Real-time PCR (rtPCR) uses species specific primers and amplification is detected by real-time monitoring of fluorescent markers at an early stage of the PCR process. The time-consuming PCR is thus reduced to a fraction of the time and a positive or negative response is avilable in much shorter time. Watanabe *et al*. (2004b) used rtPCR and *Anguilla japonica* specific primer pairs to identify unidentified eel eggs and larvae from the western Pacific Ocean. They found that other anguilliforms included in the analysis and *A. bicolor* did not amplify, but that both *A. japonica* and *A. marmorata* were amplified. *Anguilla japonica* amplified with a strong signal already in the 20th cycle whereas *A. marmorata* showed a much weaker amplification, in the 35th cycle. All identifications were counterchecked by PCR-RFLP based on sequences from adults.

There are some disadvantages with rtPCR. It remains costly and is typically only used at larger hospitals which have a high continuous throughput and need of quick results. Itoi *et al*. (2005) noted that when no signal is obtained, rtPCR cannot further ascertain the results by analyzing an amplicon with other methods, e.g. barcoding. Another issue is the weak, but false positive signal shown by *A. marmorata* which casts doubt on the specificity on the primers and therewith its usefulness in a single species environment.

Species accounts

Each species is described using a small set of standard information – diagnosis, characteristics, life history, spawning area, distribution, common names, trade, etc. The "diagnosis" is a short descriptive text of how the species can be best identified versus all other *Anguilla* using morphology whereas "characteristics" describes additional characteristics typical for the species, but not necessarily unique to the species. Life history includes general information regarding habitat and food preferences.

The common names have mainly been retrieved from the Fishbase database (www.fishbase.se), version 07/2008 in September 2008. It must be noted that common names of fish or freshwater eels typically are not regulated or standardised on a world basis. The United States is one of the few which have a naming system regulated by law. The same or similar names may occur in different languages whether linguistically close related or not. The here suggested list should not be considered authorative.

Anguilla anguilla
European eel

Diagnosis: *Anguilla anguilla* larger than 200 mm total length can be identified from all other species in the genus by a unique set of characters. Dorsal fin anterior margin typically 10.5–12.5% of TL in advance of anus. Mouth comparatively small, about one fourth of head length. Coloration plain, without distinct markings. Vertebrae 110–119; frequency distribution of vertebrae in 2775 specimens 110(1), 111(17), 112(89), 113(352), 114(719), 115(865), 116(500), 117(192), 118(36), 119(4). Maxillary tooth band without toothless area. Distance from anus to end of tail typically 5.0–5.2 times longer than distance from anus to dorsal fin insertion.

Distribution: *Anguilla anguilla* is natively found in the northeastern portion of the Atlantic Ocean but has been introduced for stocking around the world. Due to the longevity of the species those introductions may be present in nature for decades.

Synonymy: *Muraena anguilla* Linnaeus 1758, *Anguilla vulgaris* Shaw 1803, *Anguilla vulgaris fluviatilis* Rafinesque 1810, *Anguilla vulgaris lacustus* Rafinesque 1810, *Anguilla vulgaris marina* Rafinesque 1810, *Anguilla acutirostris* Risso 1827, *Anguilla latirostris* Risso 1827, *Anguilla mediorostris* Risso 1827, *Anguilla fluviatilis* Anslijin 1828, *Muraena oxyrhina* Ekström 1831, *Muraena platyrhina* Ekström 1831, *Anguilla anguilla oxycephala* de la Pylaie 1835, *Anguilla anguilla* var. *macrocephala* de la Pylaie 1835, *Anguilla anguilla* var. *ornithorhyncha* de la Pylaie 1835, *Anguilla vulgaris ornithorhincha* de la Pylaie 1835, *Anguilla vulgaris platyura* de la Pylaie 1835, *Anguilla canariensis* Valenciennes 1843, *Anguilla cloacina* Bonaparte 1846, *Anguilla septembrina* Bonaparte 1846, *Anguilla nilotica* Heckel 1846, *Anguilla migratoria* Krøyer 1846, *Anguilla platyrhynchus* Costa 1850, *Anguilla callensis* Guichenot 1850, *Anguilla aegyptiaca* Kaup 1856, *Anguilla altirostris* Kaup 1856, *Anguilla ancidda* Kaup 1856, *Anguilla bibroni* Kaup 1856, *Anguilla capitone* Kaup 1856, *Anguilla cuvieri* Kaup 1856, *Anguilla kieneri* Kaup

1856, *Anguilla marginata* Kaup 1856, *Anguilla melanochir* Kaup 1856, *Anguilla microptera* Kaup 1856, *Anguilla morena* Kaup 1856, *Anguilla platycephala* Kaup 1856, *Anguilla savignyi* Kaup 1856, *Leptocephalus brevirostris* Kaup 1856, *Anguilla nilotica* Kaup 1857, *Anguilla eurystoma* Heckel & Kner 1858, *Anguilla fluviatilis* Heckel & Kner 1858, *Anguilla marina* Nardo 1860, *Anguilla hibernica* Couch 1865, *Anguilla oblongirostris* Blanchard 1866, *Muraena anguilla maculata* Chiereghini 1872, *Anguilla brevirostris* Cisternas 1877, *Anguilla linnei* Malm 1877.

Common names: Aal (German: Austria, Germany, Switzerland; Danish: Denmark; Dutch: Netherlands; Norwegian: Norway), Ahlen (German: Germany), Ål (Danish: Denmark; Norwegian: Norway; Swedish: Sweden), Álakálvur (Faroese: Faeroe Is), Áll (Icelandic: Iceland), Álladrumbur (Faroese: Faeroe Is), Állur (Faroese: Faeroe Is), Álvinda (Faroese: Faeroe Is), Ambidda (Italian: Italy), Ambidduna (Italian: Italy), An eascann (Gaelic: Ireland; Irish: Ireland), Anchidda (Italian: Italy), Ancidda (Italian: Italy), Ancidda di sciumi (Italian: Italy), Anciddi (Italian: Italy), Ancinna (Italian: Italy), Ancioda (Italian: Italy), Angarone (Italian: Italy), Angèle (French: France), Anghí d'acqua (Italian: Italy), Anghí d'acqua de maa (Italian: Italy), Anghí d'acqua douse (Italian: Italy), Anghí d'acqua saa (Italian: Italy), Anghidda (Italian: Italy), Anghila (Rumanian: Romania), Anghilă (Rumanian: Romania), Anghilla (Italian: Italy), Anghilla de màa (Italian: Italy), Anghira (Italian: Italy), Angidda (Italian: Italy), Angolna (Hungarian [Magyar]: Hungary), Anguela (Italian: Italy), Anguella (Italian: Italy), Anguidda (Italian: Italy), Anguidda grossa (Italian: Italy), Anguidduna (Italian: Italy), Anguiello (French: France), Anguielo (French: France), Anguilla (Catalan: Spain), Anguilla (Spanish: Spain), Anguilla avocati (Italian: Italy), Anguilla europea (Spanish: Spain), Anguilla (Italian: Italy), Anguilla (Spanish: Spain), Anguilla (Italian: Switzerland), Anguilla catarrojina (Spanish: Spain), Anguilla europea (Italian: Italy), Anguilla europeana (Rumanian: Romania), Anguilla fartona (Spanish: Spain), Anguilla maresa (Spanish: Spain), Anguilla mareteca (Italian: Italy), Anguilla martina (Spanish: Spain), Anguilla pastorenca (Spanish: Spain), Anguilla pugaron (Spanish: Spain), Anguille (French: Algeria), Anguille (French: Belgium), Anguille (French: France), Anguille (French: Switzerland), Anguille argentée (French: France), Anguille d'Europe (French: France), Anguille européenne (French: France), Anguille jaune (French: France), Angula (Portuguese: Madeira Is.), Angulja (Croatian: Croatia), Angurgis (Prussian [archaic]: Germany), Ankerias (Finnish: Finland), Anzile (Italian: Italy), Astan (Manx: Isle of Man), Bisat (Italian: Italy), Bisàto (Italian: Italy), Bisato femenal (Italian: Italy), Bisato marin (Italian: Italy), Bisato papalone (Italian: Italy), Bisciatto (Italian: Italy), Blankaal (German: Germany), Bomarinque (French: France), Bouiron (French: France), Buratèl (Italian: Italy), Buratèli (Italian: Italy), Buratelo (Italian: Italy), Cacchiastrella (Italian: Italy), Canaiola (Italian: Italy), Capetune (Italian: Italy), Capillari (Italian: Italy), Capitone (Italian: Italy), Capitune (Italian: Italy), Capituni (Italian: Italy), Capomazzo (Italian: Italy), Capor (Croatian: Croatia), Cedioli (Italian: Italy), Cheli (Greek: Greece), Chéli (Greek: Greece), Chiara (Italian: Italy), Cieche (Italian: Italy), Ciríola (Italian: Italy), Cirioli (Italian:

Italy), Civelle (French: France), Common eel (English: UK), Coureuse (French: France), Crescenzia (Italian: Italy), Cuzzutella (Italian: Italy), De la riviere (French: France), Dritta (Italian: Italy), Drnák (Czech: Czech Rep), Eascann (Gaelic: Ireland; Irish: Ireland), Eel (English: Azores Is., Ireland, Isle of Man), Eiró (Portuguese: Azores Is., Madeira Is., Portugal), Enguia (Portuguese: Azores Is., Brazil, Madeira Is., Portugal), Enguia-europeia (Portuguese: Portugal), Europæisk ål (Danish: Denmark), Europäischer Aal (German: Germany), European eel (English: Kenya, Russian Fed, Taipei, UK, USA), Europeisk ål (Swedish: Sweden), Evropeiskiy ugor' (Russian: Russian Fed), Filotrotta (Italian: Italy), Fiumarola (Italian: Italy), Flussaal (German: Germany), Gelbaal (German: Germany), Gemeiner Aal (German: Germany), Gemeiner Flußaal (German: Germany), Glasállur (Faroese: Faeroe Is), H'anklyss (Arabic: Lebanon), Hel (Rumanian: Romania), Intínca (Italian: Italy), Iró (Portuguese: Azores Is., Madeira Is.), Jegula (Slovene: Slovenia), Jegulja (Croatian: Croatia; Serbian: Serbia, Montenegro; Slovene: Slovenia), Kajman (Croatian: Croatia), Kracica (Croatian: Croatia), Leptocéphale (French: France), Llsywen (Welsh: UK Engld Wal), Macchione acchione (Italian: Italy), Magliola (Italian: Italy), Magnaranocchie (Italian: Italy), Majatica (Italian: Italy), Majetica (Italian: Italy), Mar Mahi Ma'muli (Persian: Iran), Marcagghiuni (Italian: Italy), Margignou (French: France), Marmahi-e-haghighi (Persian: Iran), Meixão (Portuguese: Madeira Is.), Ngjala (Albanian: Albania), Njala (Albanian: Albania), Ogor (Rumanian: Romania), Orba (Italian: Italy), Ouhor obecný (Czech: Czech Rep), Paling (Dutch: Netherlands), Pantanina (Italian: Italy), Pibale (French: France), Piballe (French: France), Pimperneau (French: France), Pollastrella (Italian: Italy), Pougau (French: France), Pounchurote (French: France), Pounchuroto (French: France), Rechnoi ugor' (Russian: Former USSR), Resso (French: France), Retschnoi ugor (Russian: Azerbaijan, Belarus, Latvia, Ukraine), River eel (English: Former USSR), Sallura (Maltese: Malta), Schiacco (Italian: Italy), Sementara (Italian: Italy), Sili (French: France), Silien (French: France), Silver eel (English: USA), Sing eel (English: UK), Storta campagnola (Italian: Italy), Tempestina (Italian: Italy), Testoni (Italian: Italy), Thaoundella (French: France), Thaudelo (French: France), Txitxardin (Basque: Spain), Tzlofach (Hebrew: Israel), Úhor evropský (Czech: Czech Rep), Úhor obecný (Czech: Czech Rep), Úhor obycajný (Slovak: Slovakia), Úhor rícní (Czech: Czech Rep), Unagi (Japanese: Japan), Verniau (French: France), Volšák (Czech: Czech Rep), Weed eel (English: UK), Węgorz (Polish: Poland), Węgorz europejski (Polish: Poland), Yellow eel (English: USA), Yilan baligi (Turkish: Turkey), Yilan balyghi (Turkish: Turkey), Zingorra (Italian: Italy), Zmiorca (Bulgarian: Bulgaria), Zmiorka (Bulgarian: Bulgaria), Zuncurrunu (Italian: Italy), Γλαβίτσι (Greek: Greece), Καβάτσα (Greek: Greece), Καθαρόχελο (Greek: Greece), Σουβλομύταρο (Greek: Greece), Χέλι (Greek: Greece), речной угорь (Russian: Russian Fed), угорь (Russian: Russian Fed), угорь речной (Russian: Russian Fed), угорь стеклянный (Russian: Russian Fed), رگ امهرام يه امهرام (Farsi: Iran), 欧洲鳗鲡 (Simplified Chinese: China), 歐洲鰻鱺 (Traditional Chinese: China), ヨーロッパウナギ (Traditional Japanese: Japan).

Anguilla australis
Australian shortfin eel

Diagnosis: *Anguilla australis* larger than 200 mm total length can be identified from all other species in the genus by a unique set of characters. Dorsal fin anterior margin typically 0.5-2.5% of TL in advance of anus. Mouth comparatively small, about one fourth of head length. Coloration plain, without distinct markings. Vertebrae 110–119; frequency distribution of vertebrae in 2019 specimens 108(2), 109(36), 110(166), 111(492), 112(654), 113(466), 114(156), 115(44), 116(3). Prehaemal vertebrae 44–48; frequency distribution of prehaemal vertebrae in 732 specimens 44(16), 45(146), 46(360), 47(190), 48(20).

Characteristics: *Anguilla australis* is a plain-colored, medium sized species which typically grows to about 1 m and 3 kg (Jellyman 1987).

Distribution: *Anguilla australis* occurs in the subtropical to temperate waters around eastern Australia, New Zealand, and New Caledonia which also appears to be its northern limit for ascending elvers (Smith 1999).

Spawning area: The exact spawning area is not known for *Anguilla australis*, but is believed to be located somewhere around south of Solomon Islands and then, together with *A. reinhardti*, using the South Equatorial Current for westward drift towards eastern Australia (Miller *et al*. 2006) and then eastward towards New Zealand (Shiao *et al*. 2001).

Synonymy: *Anguilla australis* Richardson 1841, *Anguilla australis occidentalis* Schmidt 1928.

Common names: Almang (Agutaynen: Philippines), Anguilla australiana (Spanish: Spain), Anguille d'Australie (French: France), Australian short-finned eel (English: UK), Australisk Ål (Swedish: Sweden), Australsk ål (Danish: Denmark), Cá Chình mun (Vietnamese: Viet Nam), Casili (Cebuano: Philippines), Eel (English: USA), Endong (Kuyunon: Philippines), Enguia-australiana (Portuguese: Portugal), Gatet (Javanese: Indonesia), Igat (Tagalog: Philippines), Kasili (Cebuano: Philippines; Davawenyo: Philippines; Waray-waray: Philippines), Kibo (Ibanag: Philippines), Lembu (Javanese: Indonesia), Lumbon (Javanese: Indonesia), Moa (Malay: Indonesia), Novozelandskiy ugor' (Russian: Russian Fed), Pelus (Javanese: Indonesia), River eel (English: USA), Shortfin eel (English: Philippines, USA), Shortfinned eel (English: Australia, New Zealand), Short-finned eel (English: UK, USA), Short-finned freshwater eel (English: USA), Sidang (Javanese: Indonesia), Sidat (Javanese: Indonesia), Silver eel (English: Australia, USA), Tuna (Samoan: Samoa), Ubod-ubod (Kagayanen: Philippines), Úhoř australský (Czech: Czech Rep), Uling (Javanese: Indonesia), Węgorz australijsko-nowozelandzki (Polish: Poland), 澳洲鰻鱺 (Traditional Chinese: China), 澳洲鳗鲡 (Simplified Chinese: China), 短鰭澳洲鰻鱺 (Traditional Chinese: China), 短鳍澳洲鳗鲡 (Simplified Chinese: China).

Trade: There has been a limited export from New Zealand to Japan since 1970 (Jellyman 1979; then possibly as *Anguilla australis schmidtii*).

Anguilla bengalensis
Mottled eel

Diagnosis: *Anguilla bengalensis* larger than 200 mm total length can be identified from all other species in the genus by a unique set of characters. Dorsal fin anterior margin typically 10.5-12.5% of TL in advance of anus. Mouth comparatively large, about one third of head length. Coloration marbled. Vertebrae 106–115; frequency distribution of vertebrae in 241 specimens 106(1), 107(8), 108(19), 109(39), 110(49), 111(58), 112(40), 113(21), 114(4), 115(2); sample median of total vertebrae 109–112 (99% confidence interval for 10,000 bootstrap replicates for sample size 15). Prehaemal vertebrae 39–42; frequency distribution of prehaemal vertebrae in 243 specimens 39(4), 40(64), 41(136), 42(39).

Characteristics: *Anguilla bengalensis* reported from India reaches 120 cm (Talwar and Jingran 1991) and 6 kg (Rahman 1989) whereas Skelton (1993) reports that specimens from South Africa may reach 145 cm TL and 20.6 kg. The angling record in Malawi is 6.62 kg (Skelton 1993).

Distribution: *Anguilla bengalensis* is a tropical eel found in the Indian Ocean and surrounding fresh waters. It occurs along the African east coast and in drainages from South Africa (Scott *et al*. 1999) to Kenya, including lakes Malawi and Kariba. It is also known from Madagascar, Mauritius, Réunion (Fricke 1999). It is not reported from the Red Sea or the north-western Indian Ocean area. It occurs from Pakistan along the south Asian coast and in major drainages to Sumatra.

Synonymy: *Muraena bengalensis* Gray 1831, *Anguilla elphinstonei* Sykes1839, *Anguilla arracana* McClelland1844, *Anguilla nebulosa* McClelland1844, *Anguilla variegata* McClelland1844, *Muraena labiata* Peters1852, *Muraena macrophthalma* Peters1852.

Common names: Aarel (Malayalam: India), Aerel (Malayalam: India), African mottled eel (English: Kenya, South Africa, UK, Zambia, Zimbabwe), Afrikaanse bontpaling (Afrikaans: South Africa), Afrika-bontpaling (Afrikaans: South Africa), Afrikansk broget ål (Danish: Denmark), Aheer (Marathi: India), Ahir (Marathi: India), Anguia (Spanish: Spain), Anguilla (Spanish: Spain), Anguilla moteada (Spanish: Spain), Anguille marbrée (French: France), Anguille marbrée africaine (French: Reunion), Angula (Spanish: Spain), Banehara (Bengali: Bangladesh), Con chinh (Vietnamese: Cambodia), Enguia africana (Portuguese: Mozambique), Fiyoka (Pokomo: Kenya), Freshwater eel (English: Nepal), Gal arndha (Sinhalese: Sri Lanka), Ganga arndha (Sinhalese: Sri Lanka), Ghambi (Chuw: Mozambique [Schneider et al. 2005]), Gnalu (Malayalam: India), Hanchu mennu (Kannada: India), Hanchumeenu (Kannada: India), Harimeenu (Kannada: India), Indian longfin eel (English: India), Indian mottled eel (English: UK), Indisk broget ål (Danish: Denmark), Kabara arndha (Sinhalese: Sri Lanka), Kaha arndha (Sinhalese: Sri Lanka), Malamgulu (Telugu: India), Malugu (Telugu: India), Maniangal (Malayalam: India), Mishiligii (Oromo: Ethiopia), Mkonge (Swahili: Kenya, Tanzania), Mkunga (Other: Kenya; Swahili: Tanzania), Mlangil (Malayalam: India), Mukunga (Other: Kenya), Namunyokolo (Macu: Mozambique [Schneider et al.

2005]), Naprum (Manipuri: India), Nga-mee-toung (Burmese: Myanmar), Ngove (Tong: Mozambique [Schneider et al. 2005]), Nkunga (Nyanja: Malawi), Panga (Other: Kenya), Pol mal andha (Sinhalese: Sri Lanka), Polon arndha (Sinhalese: Sri Lanka), Porivelangu (Tamil: India), Porivilangu (Tamil: India), Pulli arndha (Sinhalese: Sri Lanka), Qurxxummi bofa fakaatu (Oromo: Ethiopia), Rajbam (Nepali: Nepal), Seram pambu (Tamil: India), Serampamboo (Tamil: India), Starry moray (English: India), Thumbi (Oriya: India), Úhoř indický (Czech: Czech Rep), Vali arndha (Sinhalese: Sri Lanka), Vallangoo (Tamil: Sri Lanka), Vellangoo (Tamil: India), Vilangu (Malayalam: India; Tamil: India), Z'amab (Creole, French: Madagascar, Reunion), Z'anguille (Creole, French: Madagascar, Reunion), रज (Nepali: India), বানহোরা (Bengali: Bangladesh), ആരല് (Malayalam: India), മലഞ്ഞില് (Malayalam: India), മലിഞ്ഞില് (Malayalam: India), വിളങ്ങ് (Malayalam: India), 东印度洋鳗鲡 (Simplified Chinese: China), 孟加拉国鳗鲡 (Simplified Chinese: China), 孟加拉鰻鱺 (Traditional Chinese: China), 東印度洋鰻鱺 (Traditional Chinese: China).

Trade: *Anguilla bengalensis* is the most common and economically important eel species in Indian freshwaters and there is a large export market for both adults and live elvers (Talwar and Jinghran 1991).

Discussion: There is some nomenclatural uncertainty over which is the valid name for the Indian Ocean "Mottled eel". Both *Anguilla bengalensis* (Gray 1831) and *Anguilla nebulosa* McClelland (1844) have been in extensive use in recent literature for the same species. There is no extant type series (Eschmeyer 1998) for *A. bengalensis*, the older name of the two, and the uncertainty may in part stem from that. For consistency, the name *Anguilla bengalensis* is chosen in this document, still recognizing the nomenclatural ambiguity.

Anguilla bicolor
Indonesian shortfin eel

Diagnosis: *Anguilla bicolor* larger than 200 mm total length can be identified from all other species in the genus by a unique set of characters. Dorsal fin insertion typically from 0.5% of TL behind the anus to 1.5% of TL in advance of anus. Mouth comparatively small, about one fourth of head length. Coloration plain, without distinct markings. Vertebrae 103–115; frequency distribution of vertebrae in 1707 specimens 103(2), 104(6), 105(18), 106(81), 107(177), 108(300), 109(419), 110(416), 111(199), 112(79), 113(7), 114(2), 115(1). Prehaemal vertebrae 41–45; frequency distribution of prehaemal vertebrae in 581 specimens 41(5), 42(120), 43(291), 44(142), 45(23).

Characteristics: *Anguilla bicolor* is a plain colored species, reaching 100 cm (Talwar and Jingran 1991).

Distribution: *Anguilla bicolor* is a tropical eel found in the Indian Ocean (Ege 1939, Kuroki *et al*. 2007). It is found along the east coast of Africa up to Arabian peninsula (Scott *et al*. 2006, Attala and Rubaia 2005), east coast of India (Talwar and Jingran 1991), north to Japan (Yamamoto *et al*. 2001) and into the Pacific. It has also been recorded from freshwater streams in Fiji (Jenkins 2003).

Spawning area: The population in the Indian Ocean spawns near the Mentawai Trench (Jespersen 1942, Kuroki *et al*. 2007) whereas the Pacific Ocean population appears associated with the Equatorial Counter Current and the South Equatorial Current (Aoyama *et al*. 1999).

Synonymy: *Anguilla bicolor* McClelland 1844, *Muraena macrocephala* Rapp 1849, *Anguilla moa* Bleeker 1850, *Muraena virescens* Peters 1852, *Anguilla mowa* Bleeker 1853, *Anguilla bleekeri* Kaup 1856, *Anguilla cantori* Kaup 1856, *Anguilla dussumieri* Kaup 1856, *Anguilla malabarica* Kaup 1856, *Anguilla amblodon* Günther 1867, *Anguilla spengeli* Weber 1912, *Anguilla pacifica* Schmidt 1928.

Common names: Amalona (English: USA), Anguilla de aleta corta (Spanish: Spain), Anguilla (Chavacano: Philippines), Anguille à nageoire courte (French: France), Anguille bicolore (French: Comoros, Madagascar, Mauritius, Mayotte, Reunion, Rodriguez, Seychelles), Bicolor eel (English: Australia), Casili (Cebuano: Philippines), Enguia de brabatana curta (Portuguese: Mozambique), Hanchu (Kannada: India), Hanchumeenu (Kannada: India), Igat (Ilokano: Philippines; Tagalog: Philippines), Indian short-finned eel (English: Australia, Papua-New Guinea, UK), Indonesian shortfin eel (English: Philippines, UK, USA), Indonesisk kortfinnet ål (Danish: Denmark), Indong (Hiligaynon: Philippines), Indong hona-san (Maranao/Samal/Tao Sug: Philippines), Indopacifisk kortfinnet ål (Danish: Denmark), Kakkuta arndha (Sinhalese: Sri Lanka), Kalu aandha (Sinhalese: Sri Lanka), Kalu arndha (Sinhalese: Sri Lanka), Kasili (Cebuano: Philippines; Davawenyo: Philippines; Waray-waray: Philippines), Kortvin-paling (Afrikaans: South Africa), Level finned eel (English: Sri Lanka), Level-finned eel (English: USA), Lever-finned eel (English: UK), Mkunga (Pokomo: Kenya; Swahili: Tanzania), Mlangil (Malayalam: India), Mukunga (Pokomo: Kenya), Namadjovo (Chuw: Mozambique [Schneider et al. 2005]), Namanhongholo (Lom: Mozambique [Schneider et al. 2005]), Namunyokolo (Macu: Mozambique [Schneider et al. 2005]), Nga-she-gya (Burmese: Myanmar), Ngove (Tong: Mozambique [Schneider et al. 2005]), Nipa-nipa (Hiligaynon: Philippines), Nkunga (Nyanja: Malawi), Northern eel (English: Australia), Palos (Tagalog: Philippines), River eel (English: Malaysia), Shortfin eel (English: India, Kenya, South Africa, Zimbabwe), Short-finned eel (English: USA), Trey chlok (Khmer: Cambodia), Tuna (Malay: Malaysia), Úhoř dvoubarevný (Czech: Czech Rep), Valuveng (Mahl: India), Vilangu (Tamil: India), Z'amab (Creole, French: Comoros, Madagascar, Mauritius, Mayotte, Reunion, Rodriguez, Seychelles), Z'anguille (Creole, French: Comoros, Madagascar, Mauritius, Mayotte, Reunion, Rodriguez), Z'anguille (Creole, French: Seychelles), മലഞ്ഞില് (Malayalam: India), മലിഞ്ഞില് (Malayalam: India), 二色鰻Traditional Chinese: China), 二色鰻 (Traditional Chinese: China), 双色鳗鲡 (Simplified Chinese: China), 太平洋双色鳗鲡 (Simplified Chinese: China), 太平洋雙色鰻鱺 (Traditional Chinese: China), 雙色鰻鱺 (Traditional Chinese: Chin

Trade: *Anguilla bicolor* is the less common and less economically important of the two eel species found in Indian freshwaters; the mottled eel, *A*. *bengalensis* is the more common. Yet, there is a market for both adults and live elvers of *A*. *bicolor* (Talwar and Jinghran 1991).

Anguilla celebesensis
Celebes longfin eel

Diagnosis: *Anguilla celebesensis* larger than 200 mm total length can be identified from all other species in the genus except *A. interioris* by a unique set of characters. Dorsal fin anterior margin typically 7.5-10.5% of TL in advance of anus. Mouth comparatively large, about one third of head length. Maxillary tooth bands broader than vomer band, without groove. Coloration marbled. Vertebrae 101–107; frequency distribution of vertebrae in 219 specimens 101(11), 102(34), 103(80), 104(66), 105(21), 106(6), 107(1); sample median of total vertebrae 103–104 (99% confidence interval for 10,000 bootstrap replicates for sample size 15).

Aoyama *et al*. (2000) found no consistent morphological differences between *Anguilla celebesensis* and *A. interioris*, only a difference in genetic distance metrics. They called for additional samples collected from more localities around New Guinea and Sulawesi before a decision can be made. Should they be found to be the same species, *A. celebesensis* Kaup (1856) has priority over *Anguilla interioris* Whitley 1938.

Synonymy: *Anguilla celebesensis* Kaup 1856, *Anguilla ancestralis* Ege 1939.

Common names: Cá chình vây dài (Vietnamese: Viet Nam), Casili (Cebuano: Philippines), Celebes langfinnede ål (Danish: Denmark), Celebes longfin eel (English: Philippines) Celebes longfin eel (English: USA), Igat (Tagalog: Philippines), Kasili (Cebuano: Philippines, Davawenyo: Philippines, Visayan: Philippines, Waray-waray: Philippines), Menguling (Malay: Indonesia), Tuna (Samoan: Samoa), Úhor celebeský (Czech: Czech Republic), 原鰻鱺 (Traditional Chinese: China), 原鳗鲡 (Simplified Chinese: China), 苏拉威西鳗鲡 (Simplified Chinese: China), 蘇拉威西鰻鱺 (Traditional Chinese: China).

Discussion: Ege (1939) noted that two specimens of *A. celebesensis* had reached the silver stage. One was in the 400–499 mm TL interval whereas the other was in the 500–799 mm TL interval.

Anguilla dieffenbachi
New Zealand longfin eel

Diagnosis: *Anguilla dieffenbachi* larger than 200 mm total length can be identified from all other species in the genus by a unique set of characters. Dorsal fin anterior margin typically 9.5-11.5% of TL in advance of anus. Mouth comparatively large, about one third of head length. Vomer tooth band broader in the middle than maxillary bands. Coloration plain, without distinct markings. Vertebrae 109–116; frequency distribution of vertebrae in 620 specimens 109(1), 110(5), 111(70), 112(191), 113(235), 114(100), 115(16), 116(2). Prehaemal vertebrae 43–47; frequency distribution of prehaemal vertebrae in 373 specimens 43(40), 44(199), 45(130), 46(3), 47(1).

Characteristics: *Anguilla dieffenbachi* is one of the largest freshwater eel species, reaching about 2 m and more than 20 kg (Todd 1980). It is a dark plain colored species without any distinct blotches or markings. The dorsal fin is long, reaching about midway from the anus to the pectoral fin insertion, which also distinguishes it from the sympatric Australian shortfin eel, *A. australis*.

Distribution: *Anguilla dieffenbachi* is endemic to New Zealand, where it lives in all habitats from the sea to the inland waters at higher altitudes (Arai *et al*. 2004). The sympatric *A. australis* is typically only found at lower altitudes.

Synonymy: *Anguilla dieffenbachi* Gray 1842.

Common names: Anguille de Nouvelle-Zélande (French: France), Longfinned eel (English: New Zealand), New Zealand longfin eel (English: UK, USA), Newzealandsk ål (Danish: Denmark), Nyzeeländsk ål (Swedish: Sweden), Úhoř novozélandský (Czech: Czech Rep), Węgorz nowozelandzki (Polish: Poland), 大鰻鱺 (Traditional Chinese: China), 大鳗鲡 (Simplified Chinese: China).

Trade: Jeffs (2003) has described the eel trade in New Zealand. All eel production (1200 metric tonnes) comes from wild eel fisheries. A handful of attempts of eel farming since the 1970s have all been abandoned. The markets are located in Europe and parts of Asia.

Anguilla interioris
Highlands longfin eel

Diagnosis: *Anguilla interioris* larger than 200 mm total length can be identified from all other species in the genus except *A. interioris* by a unique set of characters. Dorsal fin anterior margin typically 12.5-13.5% of TL in advance of anus. Mouth large, more than one third of head length. Maxillary tooth bands broader than vomer band, without groove. Coloration marbled. Vertebrae 101–107; frequency distribution of vertebrae in 14 specimens 101(1), 103(2), 104(7), 106(2), 107(2); sample median of total vertebrae 103–106 (99% confidence interval for 10,000 bootstrap replicates for sample size 15).

Ege (1939) listed only one, overlapping, character versus *A. celebesensis*, where the distance between the dorsal fin insertion and the anus is 11–15% of TL in *A. interioris* and 6–11.9% of TL in *A. celebesensis*; all other characters examined being equal. That overlapping region, 11–11.9% of TL, led Aoyama *et al*. (2000) to examine two samples, one from each of the putative species' distributions more in detail. They found no consistent morphological differences between *Anguilla celebesensis* and *A. interioris*, only a difference in genetic distance metrics. They called for additional samples collected from more localities around New Guinea and Sulawesi before a decision can be made. Should they be found to be the same species, *A. celebesensis* Kaup (1856) has priority over *Anguilla interioris* Whitley (1938).

Distribution: *Anguilla interioris* was recently only known from New Guinea (Aoyama *et al*. 2000), but is now also reported as leptocephalus larva from west of Sumatra (Aoyama 2007).

Synonymy: *Anguilla interioris* Whitley 1938.

Common names: Highlands long-finned eel (English: Papua-New Guineaea), New Guinea eel (English: Papua-New Guineaea), New Guinea-ål (Danish: Denmark), Úhoř novoguinejský (Czech: Czech Rep), 內唇鰻鱺 (Traditional Chinese: China), 内唇鳗鲡 (Simplified Chinese: China).

Anguilla japonica
Japanese eel

Diagnosis: *Anguilla japonica* larger than 200 mm total length can be identified from all other species in the genus by a unique set of characters. Dorsal fin anterior margin typically 8.5-9.5% of TL in advance of anus. Mouth comparatively small, about one fourth of head length. Maxillary tooth band with toothless area. Coloration plain, without distinct markings. Vertebrae 112–119; frequency distribution of vertebrae in 670 specimens 112(3), 113(13), 114(80), 115(169), 116(207), 117(139), 118(45), 119(14). Distance from anus to end of tail typically 5.6–6.0 times longer than distance from anus to dorsal fin insertion.

Characteristics: *Anguilla japonica* is one of the smaller *Anguilla* species reaching 1.3 m. Specimens larger than 60 cm are typically females (Matsui 1984).

Distribution: *Anguilla japonica* have its natural distribution in the north western Pacific Ocean. It is recorded from VietNam, China, Korea, Japan, and northern Philippines. Its eastern distribution is delimited by a sharp saline gradient at about 140°E at high sea. The southern limit is the northern Philippines.

Spawning area: The spawning area of *Anguilla japonica* is probably located around seamounts in the north western Pacific Ocean, west of Guam, approximately at 15ºN, 140ºE (Tsukamoto 1992, Tsukamoto *et al*. 2002). The recruitment period for the east coast of Japan is from October to May and for the south coast of Japan from January to June (Sugeha *et al*. 2001).

Synonymy: *Anguilla japonica* Temminck & Schlegel 1847, *Anguilla remifera* Jordan & Evermann 1902.

Common names: Anguilla (Spanish: Spain), Anguilla japonesa (Spanish: Spain), Anguilla giapponese (Italian: Italy), Anguille du Japon (French: France), Asiatischer Aal (German: Germany), Bái shàn (Mandarin: China), Bat sin (Cantonese: Hong Kong), Cá chình Nhật (Vietnamese: Viet Nam), Casili (Bikol: Philippines; Cebuano: Philippines), Eel (English: USA), Enguia (Portuguese: Brazil), Enguia-japonesa (Portuguese: Portugal), Enguila japonesa (Portuguese: Portugal), Freshwater eel (English: Thailand), Igat (Tagalog: Philippines), Japanese eel (English: Hong Kong, UK, USA; Tagalog: Philippines), Japaninankerias (Finnish: Finland), Japanischer Aal (German: Germany), Japanse paling (Dutch: Netherlands), Japansk ål (Danish: Denmark; Icelandic: Iceland; Swedish: Sweden), Japon yilan baligi (Turkish:

Turkey), Jegulja japanska (Serbian: SerbiaMontenegro), Kabayaki (Japanese: Japan), Kasili (Cebuano: Philippines; Davawenyo: Philippines; Waray-waray: Philippines), Mán lí (Mandarin: China), Man ue (Cantonese: Hong Kong), Mán yú (Mandarin: China), Paen-jang-? (Korean: Korea Rep), Pla lai yee pun (Thai: Thailand), Rí b?n mán lí (Mandarin: China), Ubod (Hiligaynon: Philippines), Úhoř japonský (Czech: Czech Rep), Unagi (Japanese: Japan), Węgorz japonski (Polish: Poland), Yaponskiy ugor' (Russian: Russian Fed), ปลาไหลปุ่น (Thai: Thailand), ウナギ (Japanese: Japan), 뱀장어 (Korean: Korea Rep), 日本鰻 (Traditional Chinese: China), 日本鰻鱺 (Traditional Chinese: China), 日本鰻 (Traditional Chinese: China), 日本鰻鰼 (Simplified Chinese: China).

Trade: *Anguilla japonica* is the most widely traded eel species in the world, where the global production of that species alone is almost tenfold of all the other species combined (see Table 5).

Discussion: Okamura (2001) examined the performance of a discriminant function analysis using four morphometric distances for identifying *Anguilla japonica* versus *A. anguilla*. Their method allowed the correct classification of more than 90% of specimens, using molecular data for verification.

In the natural habitat of *Anguilla japonica* there are large quantities of introduced and stocked European eel, *A. anguilla* (Okamura 2004). It is not known whether these two species can hybridize in nature, but it has been shown by Okamura *et al*. (2004) that larvae can be produced by artificial insemination and that the larvae may survive for more than 30 days after hatching. Recent studies (Okamura *et al*. 2008) have, however, shown a decline in abundance of non-native *Anguilla* species.

Anguilla borneensis
Indonesian longfinned eel

Diagnosis: *Anguilla borneensis* larger than 200 mm total length can be identified from all other species in the genus by a unique set of characters. Dorsal fin anterior margin typically 10.5–13.5% of TL in advance of anus. Mouth comparatively large, about one third of head length. Maxillary tooth band with toothless area. Coloration plain, without distinct markings. Vertebrae 103–108; frequency distribution of vertebrae in 103 specimens 103(2), 104(15), 105(37), 106(32), 107(13), 108(4); sample median of total vertebrae 105–106 (99% confidence interval for 10,000 bootstrap replicates for sample size 15). Prehaemal vertebrae 39–42; frequency distribution of prehaemal vertebrae in 104 specimens 39(5), 40(40), 41(55), 42(4).

Distribution: *Anguilla borneensis* has the smallest distribution of all freshwater eels and is endemic to the eastern coast of Borneo.

Synonymy: *Anguilla borneensis* Popta 1924.

Common names: Belud (Malay: Malaysia), Indonesian longfinned eel (English: UK), Sinsilud (Malay: Malaysia), Sydøstasiatisk ål (Danish: Denmark), Úhoř bornejský (Czech: Czech Rep), Úhoř sundský (Czech: Czech Rep), 加里曼丹鰻鱺 (Traditional Chinese: China), 加里曼丹鰻鰼 (Simplified Chinese: China), 印尼鰻鱺 (Traditional Chinese: China), 印度尼西亚鰻鰼 (Simplified Chinese: China).

Trade: Indonesian law prohibits export of individuals less than 5 mm [sic] of *Anguilla nebulosa* and *A. borneensis* (Tjakrawidjaja 2001), which if reinterpreted as an error for 50 mm then in effect also is an export ban on glass eels.

Discussion: This species has also been erroneously cited under the name *Anguilla malgumora*. This error was kindly pointed out by Dr. Maurice Kottelat (*in litt*.).

The holotype of *Anguilla malgumora* Kaup (1856), MNHN A-9954 (Bauchot *et al.* 1993) was examined and discussed by Ege (1939). While Ege could not identify the type with any particular species, Ege (1939:139) concluded "In any case that Borneo was the country of origin of the specimen must rest on some misunderstanding".

Bauchot *et al.* (1993:95) writes on the holotype of *Anguilla malgumora* Kaup: "*D'apres P.H.J. Castle, c'est l'espèce décrite* A. borneensis *par Popta, 1925 Zool. Meded., 8: 73–76, dont elle devient ainsi le senior synonyme.*" ["According to P.H.J. Castle, it is the species *A. borneensis* described by Popta, 1925 Zool. Meded., 8: 73–76, of which it thus becomes the senior synonym". Author's translation]. This epithet suggested by Castle was used by Smith (1999), Lin *et al.* (2001, 2002, 2005), and in a circulated pre-print electronic version 1.0 of this document. However, Castle's statement is not supported by any published data and is not followed here.

The correct name for the species erroneously cited as *Anguilla malgumora* should be *Anguilla borneensis*.

Anguilla marmorata
Marbled giant eel

Diagnosis: *Anguilla marmorata* larger than 200 mm total length can be identified from all other species in the genus by a unique set of characters. Dorsal fin anterior margin typically 15.5-16.5% of TL in advance of anus. Mouth comparatively large, about one third of head length. Maxillary tooth band with toothless area. Coloration marbled. Vertebrae 100–110; frequency distribution of vertebrae in 2011 specimens 100(2), 101(2), 102(7), 103(83), 104(298), 105(545), 106(600), 107(348), 108(91), 109(28), 110(7); sample median of total vertebrae 105–107 (99% confidence interval for 10,000 bootstrap replicates for sample size 15). Prehaemal vertebrae 39–43; frequency distribution of prehaemal vertebrae in 833 specimens 39(2), 40(134), 41(471), 42(215), 43(11). The caudal fin of the glass eels (elvers) have a black tip (Ege 1939, Lee *et al*. 1997, Robinet *et al*. 2003)

Characteristics: *Anguilla marmorata* is one of the largest species of *Anguilla*, reaching 2 m and more than 20 kg (Ege 1939, Castle 1984).

Distribution: *Anguilla marmorata* is the most wide-spread of all freshwater eels and is found in the Indo-Pacific, from East Africa and India, north to southern Japan (Smith 1999), and east to Tahiti (Lecomte-Finiger *et al*. 2000) and the Galápagos Islands (McCosker *et al*. 2003). It is recorded from freshwater streams in Fiji (Jenkins 2003), and is the single anguillid species in Laos (Kottelat 2001). Minegishi *et al*. (2008) reported that *A. marmorata* has multiple reciprocally monophyletic populations: (i) the North Pacific (from Japan to Sulawesi), (ii) the South

Pacific (from Papua New Guinea to Tahiti), (iii) the Indian Ocean (from Sumatra to Madagascar), and (iv) Guam (including Micronesia) populations. Robinet *et al*. (2008) suggested that the spawning area of the western Indian Ocean population is located between Madagascar and the Mascarenes. Due to the similarity with *A bengalensis* the distribution in the northeastern parts of the Indian Ocean needs further sampling, possibly using molecular identification.

Life history: Compared to other species found at the same place, *Anguilla marmorata* is typically found further inland also at higher altitudes, and inhabits deeper parts of rivers often with rocks and boulders (Skelton 1993).

Synonymy: *Anguilla marmorata* Quoy and Gaimard 1824 *Anguilla marmolata* Quoy & Gaimard 1824, *Anguilla mauritiana* Bennett 1831, *Muraena manillensis* Bleeker 1864, *Anguilla johannae* Günther 1867, *Anguilla hildebrandti* Peters 1881.

Common names: Almang (Agutaynen: Philippines), Anguilla (Chavacano: Philippines), Anguilla moteada gigante (Spanish: Spain), Anguille (French: Reunion), Anguille marbrée (French: Comoros, Fr Polynesia, Madagascar, Mauritius, Mayotte, Reunion, Rodriguez), Antong Tunleir (Khmer: Cambodia), Cá chình (Vietnamese: Viet Nam), Casili (Borirawan; Bikol: Philippines; Cebuano: Philippines), Congre (French: Reunion), Diria (Fijian: Fiji), Eel (English: Philippines), Endong (Kuyunon: Philippines), Enguia gigante (Portuguese: Mozambique), Gateng (Javanese: Indonesia), Ghambi (Chuw: Mozambique [Schneider et al. 2005]), Giant long-finned eel (English: Australia, Papua-New Guinea), Giant mottled eel (English: Philippines, South Africa, UK), Grande anguille marbrée (French: France), Igat (Tagalog: Philippines), Indong honasan (Maranao/Samal/Tao Sug: Philippines), Kaee hinu (Marquesan: Fr Polynesia), Kasili (Cebuano: Philippines; Davawenyo: Philippines; Waray-waray: Philippines; Visayan: Philippines), Kuee (Marquesan: Fr Polynesia), Lembu (Javanese: Indonesia), Lumbon (Javanese: Indonesia), Madagascar mottled eel (English: South Africa, Zimbabwe), Madagaskar-bontpaling (Afrikaans: South Africa), Marbled eel (English: China Main, Fiji, Korea Rep), Marmoreret kæmpeål (Danish: Denmark), Moa (Javanese: Indonesia), Moa kembang (Malay: Indonesia), Namunyokolo (Macu: Mozambique [Schneider et al. 2005]), Ngove (Tong: Mozambique [Schneider et al. 2005]), Ô-unagi (Japanese: Japan), Pa lai fai fa (Laotian: Laos), Palos (Tagalog: Philippines), Pangitan (Kagayanen: Philippines), Pba lat meow (Laotian: Laos), Pelus (Javanese: Indonesia), Pubukangbinhi (Tagalog: Philippines), Puhi pa'a (Tahitian: Fr Polynesia), Puhi poa (Tahitian: Fr Polynesia), Reus-bontpaling (Afrikaans: South Africa), Sidang (Javanese: Indonesia), Sidat (Javanese: Indonesia), Talunasan (Kapampangan: Philippines), Tigitol (Carolinian: N Marianas), Tuna (Samoan: Samoa; Tahitian: Fr Polynesia, Tahiti), Úhoř mramorovaný (Czech: Czech Rep), Uling (Javanese: Indonesia), Uling asu (Javanese: Indonesia), Uling kirik (Javanese: Indonesia), Xanfitima (Rong: Mozambique [Schneider et al. 2005]), Z'amab (Creole, French: Comoros, Madagascar, Mauritius, Mayotte, Reunion), Z'anguille (Creole, French: Comoros, Madagascar, Mauritius, Mayotte, Reunion), オオウナギ (Japanese: Japan), 무태장어 (Korean: Korea Rep), 毛里求斯鰻鱺 (Traditional Chinese: China), 毛里求斯鳗鲡 (Simplified Chinese:

China), 花鰻鱺 (Traditional Chinese: China), 花鳗鲡 (Simplified Chinese: China), 鱸鰻 (Traditional Chinese: China), 鲈鳗 (Simplified Chinese: China).

Trade: *Anguilla marmorata* is of international importance and local economic importance throughout its geographic range.

Anguilla megastoma
Polynesian longfin eel

Diagnosis: *Anguilla megastoma* larger than 200 mm total length can be identified from all other species in the genus by a unique set of characters. Dorsal fin anterior margin typically 10.5-11.5% of TL in advance of anus. Mouth comparatively large, more than one third of head length. Maxillary tooth bands broader than vomer band, without groove. Coloration marbled or plain (10% of all specimens). Vertebrae 108–116; frequency distribution of vertebrae in 231 specimens 108(1), 109(1), 110(7), 111(25), 112(61), 113(84), 114(41), 115(8), 116(3); sample median of total vertebrae 112–113 (99% confidence interval for 10,000 bootstrap replicates for sample size 15).

Characteristics: *Anguilla megastoma* reaches 90 cm (New Caledonia; Laboute and Grandperrin 2000) and shows a unique variation in colour pattern, with specimens showing all gradations from a plain colour to a distinct variegated pattern. About one tenth of the specimens lacks any trace of variegated patterns (Ege 1939). The mouth is large and the lips typically are well developed, reaching the lower margin of the eye (Figures 51–53).

Distribution: Western and Central Pacific Ocean. Recorded from freshwater streams in Fiji (Jenkins 2003, McCosker *et al*. 2003).

Synonymy: *Anguilla megastoma* Kaup 1856.

Common names: Anguille de montagne (French: Fr Polynesia), Pacific long-finned eel (English: Australia, Papua-New Guinea), Polynesian longfin eel (English: USA), Polynesian longfinned eel (English: UK), Polynesisk ål (Danish: Denmark), Puhi maua (Tahitian: Fr Polynesia), Rere ‘ie ‘ie (Tahitian: Fr Polynesia), Tuna (Tahitian: Tahiti), Úhoř polynéský (Czech: Czech Rep), 大口鰻鱺 (Traditional Chinese: China), 大口鳗鲡 (Simplified Chinese: China)

Anguilla mossambica
African longfin eel

Diagnosis: *Anguilla mossambica* larger than 200 mm total length can be identified from all other species in the genus by a unique set of characters. Dorsal fin anterior margin typically 13.5-15.5% of TL in advance of anus. Mouth comparatively large, about one third of head length. Maxillary tooth band without toothless area. Coloration plain, without distinct markings. Vertebrae 100–106; frequency distribution of vertebrae in 515 specimens 100(8), 101(53), 102(123), 103(182), 104(106), 105(39), 106(4); sample median of total vertebrae 102–104 (99% confidence inter-

val for 10,000 bootstrap replicates for sample size 15). Prehaemal vertebrae 39–42; frequency distribution of prehaemal vertebrae in 520 specimens 39(30), 40(232), 41(233), 42(25).

Characteristics: *Anguilla mossambica* reaches 120 cm and 5.7 kg (Skelton 1993).

Distribution: *Anguilla mossambica* is found in waters around the south-western Indian Ocean. It is abundantly recorded from African streams from east of Cape Agulhas (near Cape Town), South Africa north to Kenya (Scott *et al*. 2006). It has, however, not been recored from the Agulhas National Park, South Africa (Russel and Impson 2006). It is also recorded from Madagascar and the Mascarene Islands (Fricke 1999)

Synonymy: *Muraena mossambica* Peters 1852, *Anguilla delalandi* Kaup 1856, *Anguilla capensis* Kaup 1860.

Common names: African longfin eel (English: Kenya, UK, USA), Afrikanischer Langflossenaal (German: Germany), Afrikansk ål (Danish: Denmark), Anguilla de aleta larga de Africa (Spanish: Spain), Anguille à longue nageoire (French: France), Anguille du Mozambique (French: Comoros, Madagascar, Mauritius, Mayotte, Reunion), Enguia moçambicana (Portuguese: Mozambique), Geelbekpaling (Afrikaans: South Africa), Longfin eel (English: Kenya, South Africa, Zimbabwe), Mkunga (Pokomo: Kenya; Swahili: Tanzania), Mukunga (Pokomo: Kenya), Namanhongholo (Lom: Mozambique [Schneider et al. 2005]), Namunyokolo (Macu: Mozambique [Schneider et al. 2005]), Nghoyo (Chuw: Mozambique [Schneider et al. 2005]), Ngove (Tong: Mozambique [Schneider et al. 2005]), Nikhonono (Chuw: Mozambique [Schneider et al. 2005]), Úhoř mosambický (Czech: Czech Rep), Xanfitima (Rong: Mozambique [Schneider et al. 2005]), Z'amab (Creole, French: Comoros, Madagascar, Mauritius, Mayotte, Reunion), Z'anguille (Creole, French: Comoros, Madagascar, Mauritius, Mayotte, Reunion), угорь мозамбийкский (Russian: Russian Fed), 莫桑比克鰻鱺 (Traditional Chinese: China), 莫桑比克鰻鰵 (Simplified Chinese: China).

Anguilla obscura
Pacific shortfinned eel

Diagnosis: *Anguilla obscura* larger than 200 mm total length can be identified from all other species in the genus by a unique set of characters. Dorsal fin anterior margin typically 2.5-4.5% of TL in advance of anus. Mouth comparatively large, about one third of head length. Coloration plain, without distinct markings. Vertebrae 101–108; frequency distribution of vertebrae in 608 specimens 101(5), 102(28), 103(144), 104(239), 105(153), 106(36), 107(2), 108(1). Prehaemal vertebrae 40–43; frequency distribution of prehaemal vertebrae in 600 specimens 40(31), 41(268), 42(276), 43(25).

Distribution: Pacific Ocean. Recorded from freshwater streams in Fiji (McCosker *et al*. 2003) and Tahiti (Lecomte-Finiger *et al*. 2000).

Synonymy: *Anguilla obscura* Günther 1872.

Common names: Anguille de vase (French: Fr Polynesia), Anguille sombre (French: Fr Polynesia), Brown eel (English: Fiji), Malavo (Fijian: Fiji), Pacific short-finned eel (English: Australia, Papua-New Guinea), Pacific shortfinned eel (English: UK), Pacific shortfinned freshwater eel (English: USA), Puhi (Rapa: Fr Polynesia), Puhi vari (Tahitian: Fr Polynesia), Short-finned eel (English: USA), South Pacific eel (English: Australia), Sydpacifisk ål (Danish: Denmark), Ta'a repo (Tahitian: Fr Polynesia), Tuna (Tahitian: Tahiti), Úhoř tichooceánský (Czech: Czech Rep), 灰鰻鱺 (Traditional Chinese: China), 灰鳗鲡 (Simplified Chinese: China).

Anguilla reinhardti
Speckled longfin eel

Diagnosis: *Anguilla reinhardti* than 200 mm total length can be identified from all other species in the genus by a unique set of characters. Dorsal fin anterior margin typically 9.5-11.5% of TL in advance of anus. Mouth comparatively small, about one fourth of head length. Maxillary tooth band with toothless area. Coloration plain, without distinct markings. Vertebrae 104–110; frequency distribution of vertebrae in 413 specimens 104(1), 105(6), 106(36), 107(111), 108(157), 109(92), 110(10).

Characteristics: *Anguilla reinhardti* is one of the largest anguillid species, attaining a size up to 1650 mm, 22 kg, and growing more rapidly than co-existing and native *A. dieffenbachi* which may possibly reach similar sizes (Chisnall 2000).

Distribution: Southwestern Pacific Ocean, mainly along the east coast of Autralia. Recently also recorded more frequently in New Zealand freshwater streams (Chisnall 2000). Whether this is outside its native range is perhaps not yet understood, as New Zealand specimens have been found in museum collections from at least 1958.

Spawning area: The exact spawning area is not known for *Anguilla reinhardti*, but is believed to be located somewhere around south of Solomon Islands and then, together with *A. australis*, using the South Equatorial Current for westward drift towards eastern Australia (Miller *et al*. 2006).

Synonymy: *Anguilla reinhardti* Steindachner 1867.

Common names: Australian longfinned eel (English: UK), Conger eel (English: Australia), Longfin eel (English: USA), Longfinned eel (English: Australia), Marbled eel (English: Australia), Spættet ål (Danish: Denmark), Speckled longfin eel (English: UK, USA), Spotted eel (English: Australia), Úhoř Reinhardtův (Czech: Czech Rep), 宽鳍鳗鲡 (Simplified Chinese: China), 寬鰭鰻鱺 (Traditional Chinese: China).

Anguilla rostrata
American eel

Diagnosis: *Anguilla rostrata* larger than 200 mm total length can be identified from all other species in the genus by a unique set of characters. Dorsal fin anterior margin typically 8.5-9.5% of TL in advance of anus. Mouth comparatively small, about one fourth of head length. Maxillary tooth band with toothless area.

Coloration plain, without distinct markings. Vertebrae 103–111; frequency distribution of vertebrae in 865 specimens 103(1), 104(8), 105(45), 106(184), 107(275), 108(222), 109(96), 110(31), 111(3).

Distribution: Along the coast of western Atlantic Ocean, from northern South America to Canada and Greenland. Less than 10% of *Anguilla* collected in Iceland are typically identified as *A. rostrata*, which have suggested to be hybrids (Albert *et al*. 2006).

Synonymy: *Muraena argentea* Lesueur 1817, *Muraena bostoniensis* Lesueur 1817, *Muraena macrocephala* Lesueur 1817, *Muraena rostrata* Lesueur 1817, *Muraena serpentina* Lesueur 1817, *Anguilla blephura* Rafinesque 1817, *Anguilla chrisypa* Rafinesque 1817, *Anguilla laticanda* Rafinesque 1818, *Anguilla laticauda* Rafinesque 1818, *Anguilla aterrima* Rafinesque 1820, *Anguilla lutea* Rafinesque 1820, *Anguilla xanthomelas* Rafinesque 1820, *Anguilla tenuirostris* DeKay 1842, *Anguilla cubana* Kaup 1856, *Anguilla macrops* Kaup 1856, *Anguilla novaeorleanensis* Kaup 1856, *Anguilla novaeterrae* Kaup 1856, *Anguilla punctatissima* Kaup 1856, *Anguilla texana* Kaup 1856, *Anguilla wabashensis* Kaup 1856, *Anguilla tyrannus* Girard 1858, *Leptocephalus grassii* Eigenmann & Kennedy 1902.

Common names: Aal (Dutch: NethAntilles), American eel (English:, Belize Cuba, Puerto Rico, UK, USA), Amerikaanse aal (Dutch: Netherlands), Amerikanankerias (Finnish: Finland), Amerikanischer Aal (German: Germany), Amerikansk ferskvandsål (Danish: Denmark), Amerikansk ål (Danish: Denmark; Swedish: Sweden), Amerikanskiy ugor' (Russian: Russian Fed), Anguilla (Spanish: Costa Rica, Cuba, Puerto Rico, Mexico, Spain), Anguilla americana (Italian: Italy), Anguille (French: Martinique), Anguille américaine (French: France), Anguille d'Amérique (French: Can Quebec, France), Common eel (English: Barbados, Neth. Antilles, Puerto Rico), Eel (English: UK), Elver (joven) (English: Cuba), Enguia (Portuguese: Brazil), Enguia-americana (Portuguese: Portugal), Freshwater eel (English: Cuba), Moringa cetkowana (Polish: Poland), Paling (Dutch: NethAntilles), Silver eel (English: UK), Úhoř americký (Czech: Czech Rep), Węgorz amerykanski (Polish: Poland), угорь американский (Russian: Russian Fed), 美洲鰻鱺 (Traditional Chinese: China), 美洲鳗鲡 (Simplified Chinese: China).

Incertae sedis

Scientific names of uncertain placement

There are several more scientific names which have been associated with freshwater eels, but which have not been decidedly linked to other species currently considered valid taxa, and/or not included in any recent comprehensive study of eels. The following list of available names (in alphabetical order) associated with the freshwater eels (Anguillidae) was compiled (15 September 2008) from the on-line version of Eschmeyer's (1998) 'Catalog of Fishes' (available at www.calacademy.org, updated 29 August 2008), FishBase (www.fishbase.se, version 07/2008) and other sources. Eschmeyer (1998) lists some additional names that are not available and hence not included here.

Anguilla anacamptoentera Balsamo-Crivelli & Maggi 1872. Italy.

Muraena anguilla anguillechien Schneider in Bloch & Schneider 1801. No locality. No types known.

Anguilla avisotis Richardson 1845. Canton, China. No types known.

Anguilla breviceps Chu & Jin 1984. China. Holotype: SFC 57-2318.

Anguilla caeca Smith 1904. Western Atlantic, 60 miles south of Noman's Land, Massachusetts, U.S.A. Holotype: USNM 51483 (lost).

Anguilla eurylaema Kaup 1856. No locality. Holotype: MNHN (not found; Bauchot *et al*. 1993:124).

Anguilla fasciata Kaup 1856. No locality. Holotype: RMNH (not found).

Anguilla foochowensis Chu & Jin 1984. Fuzhou, Fujian, China. Holotype: SFC 57-4104.

Leptocephalus inferior Shen 1963. Estuary of the Tam-sui River. Syntypes: NTUM (2). Larvae, may belong to a species of *Anguilla*.

Anguilla isinglaena Kaup 1856. No locality.

Anguilla macroptera McClelland 1844. Zhoushan, Zhejiang,China.

Anguilla nigricans Chu & Wu 1984. Xiamen, Fujian, China. Holotype: SFC 60-9452.

Anguilla orthoentera Balsamo-Crivelli & Maggi 1872. Italy.

Anguilla vulgaris platirostris Döderlein 1879.

Anguilla porphyrea Günther (ex Hodgson 1861). Rosi Khola, a clear hill-stream, central region of Nepal. No types known.

Anguilla sinensis McClelland 1844. Zhoushan, Zhejiang,China.

Acknowledgments

There are numerous colleagues who have helped me produce this guide and I am deeply grateful to all the kind and enthusiastic assistance I have received! Dr. Håkan Wickström, Swedish Board of Fisheries kindly provided information on glass eels, provided numerous images, and commented on drafts of both the illustrations and the manuscript; Dr. Akihiro Okamura, Irago Institute Co., Ltd. generously provided literature; Dr. Shun Watanabe, Division of Fisheries Ecology, Ocean Research Institute, The University of Tokyo made several helpful comments on an early version of the identification key; Dr. Jeffrey T. Williams, Division of Fishes, Department of Vertebrate Zoology, Smithsonian; Mr. Anders Asp, Swedish Board of Fisheries; Dr. Guy Verreault, Ministère des Ressources Naturelles et de la Faune, Canada; Mr Jason Schratwiser, International Game Fish Association; and Dr Michael Norén and Mr Liao Te-Yu, Swedish Museum of Natural History (NRM) all generously allowed me to use their photographs. Mr. Carl Mattsson tested an early version of the identification key and together with Mrs. Bodil Kajrup both at NRM radiographed eels for this purpose, Mr. Esa Jernstedt and colleagues at Sensec AB kindly allowed me to test their x-ray equipment as did Mr. Svante Hull and colleagues at the Swedish Customs, Arlanda Airport. Dr. Peder Rask Møller and Prof. Jørgen Nielsen, both at the Zoological Museum, University of Copenhagen, kindly informed me that Wilhelm Ege's raw data still are not located and I thank Dr. Peder Rask Møller for hand carrying eel specimens in their care to Stockholm. My gratitude to Ms Mercedes Lasso, Ministro de Industria, Turismo y Comercio and Mr. Carlos Ibero Solana, Asesores Técnicos de Medio Ambiente, Spain for providing 'angulas'. Dr. Willem Dekker, Institute for Marine Resources & Ecosystem Studies, IJmuiden, The Netherlands; Dr William Eschmeyer, California Academy of Sciences, San Francisco; Dr. Maurice Kottelat, Cornol, Switzerland; Dr. Sven Kullander, NRM; Dr. Gregory Maes, Laboratory of Animal Diversity and Systematics, Katholieke Universiteit Leuven; Dr. Stefan Palm, Swedish Board of Fisheries have all kindly read and helpfully commented on late drafts of the guide. Dr. Dario Zuccon, NRM helped me with interpretation of several molecular papers and provided detailed laboratory protocols for the COI and 16S rRNA genes. The 47 base-pair region was identified by the author, the forward and reverse primers were developed by Dr Dario Zuccon, and the PCR protocol was developed and implemented by Dr Martin Irestedt, NRM. I have discussed various aspects of the content with several people, where I particularly would like to mention Dr Bo Delling, Dr Jan Ohlson and Mr Magnus Gelang all at NRM. Several drafts have been circulated for review within the EU Commission, viz. CITES Enforcement Group and in the CITES Scientific Review Group. Finally, I wish to express my sincere gratitude to Mrs Yvonne Lundell at the Swedish Environmental Protection Agency for logistics, improvements on the final versions of the manuscript, and her continuously enthusiastic support and feedback. This study was financed by the Swedish Environmental Protection Agency. Thank you all!

References

Albert, V., B. Jónsson, and L. Bernatchez. 2006. Natural hybrids in Atlantic eels (*Anguilla anguilla*, *A. rostrata*): evidence for successful reproduction and fluctuating abundance in space and time. Molecular Ecology 15: 1903–1916.

Altschul, S.F., W.G. Gish, W. Miller, E.W. Myers, D.J. Lippman. 1990. Basic local Alignment search tool. Journal of Molecular Biology 215: 403–410.

Anonymous. 2004. Eel industry faces major crisis. BBC News. (http://news.bbc.co.uk/1/hi/northern_ireland/4000527.stm; retrieved 6 November 2008).

Anonymous. 2006. Police net suspected eel poacher. BBC News. (http://news.bbc.co.uk/2/hi/uk_news/england/kent/4908190.stm; retrieved 10 november 2008).

Anonymous. 2007. Smugglers set sights on lucrative seafood. By asahi.com. The Asahi Shimbun. (http://www.infoyu.net/NewsCenter/MarketTrade/07-6-18-36.html; retrieved 10 November 2008)

Aoyama, J., and K. Tsukamoto. 1997. Evolution of the freshwater eels. Naturwissenschaften 84: 17–21.

Aoyama, J., Ishikawa, S., Otake, T., Mochioka, N., Suzuki, Y., Watanabe, S., Shinoda, A., Inoue, J., Lokman, P. M., Inagaki, T., Oya, M., Hasumoto, H., Kubokawa, K., Lee, T. W., Fricke, H. and Tsukamoto, K. 2001. Molecular approach to species identification of eegs with respect to determination of the spawning site of the Japanese eel *Anguilla japonica*. Fisheries Science 67: 761–763.

Aoyama, J., M. Nishida, and K. Tsukamoto. 2001. Molecular phylogeny and evolution of the freshwater eel, genus *Anguilla*. Molecular Phylogenetics and Evolution 20(3): 450–459.

Aoyama, J., N. Mochioka, T. Otake, S Ishikawa, Y. Kawakami, P.[H.J.] Castle, M. Nishida, and K. Tsukamoto. 1999. Distribution and dispersal of anguillid leptocephali in the western Pacific Ocean revealed by molecular analysis. Marine Ecology Progress Series 188: 193–200.

Aoyama, J., S. Watanabe, S. Ishikawa, M. Nishida, and K. Tsukamoto. 2000. Are morphological characters distinctive enough to discriminate between two species of freshwater eels, *Anguilla celebesensis* and *A. interioris*? Ichthyological Research 47(2): 157–161.

Aoyama, J., S. Wouthuyzen, M.J. Miller, T. Inagaki, and K. Tsukamoto. 2003. Short-distance spawning migration of tropical freshwater eels. Biological Bulletin 204: 104–108.

Aoyama, J., S. Wouthuyzen, M.J. Miller, Y. Minegishi, M. Kuroki, S.R. Suharti, T. Kawakami, K.O. Sumardiharga, and K. Tsukamoto. 2007.

Distribution of leptocephali of the freshwater eels, genus *Anguilla*, in the waters off west Sumatra in the Indian Ocean. Environmental Biology of Fishes 80: 445–452.

Aoyama, J., Watanabe, S., Nishida, M. and Tsukamoto, K. 2000. Discrimination of catadromous eel species, genus *Anguilla*, using PCR-RFLP analysis of the mitochondrial 16SrRNA domain. Transactions of the American Fisheries Society 129: 873–878.

Arai, T., A. Kotake, P.M. Lokman, M.J. Miller, K. Tsukamoto. 2004. Evidence of different habitat use by New Zealand freshwater eels *Anguilla australis* and *A. dieffenbachii*, as revealed by otolith microchemistry. Marine Ecology Progress Series 266: 213–225.

Arai, T., D. Limbong, T. Otake, K. Tsukamoto. 2001a. Recruitment mechanisms of tropical eels *Anguilla* spp. and implications for the evolution of oceanic migration in the genus *Anguilla*. Marine Ecology Progress Series 216: 253–264.

Arai, T., J. Aoyama, S. Ishikawa, M.J. Miller, T. Otake, T. Inagaki, T. Tsukamoto. 2001b. Early life history of tropical *Anguilla* leptocephali in the western Pacific Ocean. Marine Biology 138: 887–895.

Avise, J.C. 2000. Phylogeography: The history and formation of species. Harvard University Press, Cambridge, MA. 464 pp.

Avise, J.C., and D. Walker. 2000. Abandon all species concepts? A response. Conservation Genetics 1: 77–80.

Avise, J.C., G.S. Helfman, N.C. Saunders, and L.S. Hales. 1986. Mitochondrial DNA differentiation in North Atlantic eels: population genetic consequences of an unusual life history pattern. Proceedings of the National Academy of Sciences of the United States of America 83(12): 4350–4354.

Barbin, G.P., and J.D. Mcleave. 1997. Fecundity of the American eel *Anguilla rostrata* at 45° N in Maine, U.S.A. Journal of Fish Biology 51: 840–847.

Bast, H.-D., and B. Strehlow. 1990. Length composition and abundance of eel larvae, *AnguilIa anguilla* (Anguilliformes: Anguillidae), in the Iberian Basin (northeastern Atlantic) during July–September 1984. Helgoländer Meeresuntersuchungen 44: 353–361.

Bastrop, R., B. Strehlow, K. Jürss, and C. Sturmbauer. 2000. A new molecular phylogenetic hypothesis for the evolution of freshwater eels. Molecular Phylogenetics and Evolution 14(2): 250–258.

Bauchot M.L., M. Desoutter, P.H.J. Castle. 1993. Catalogue critique des types de poissons du Muséum national d'Histoire naturelle. Ordre des Anguilliformes et des Saccopharyngiformes. Cybium 17: 91–151.

Bonhommeau, S., E. Chassot, and E. Rivot. 2008. Fluctuations in European eel (*Anguilla anguilla*) recruitment resulting from environmental changes in the Sargasso Sea. Fisheries Oceanography 17(1): 32–44.

Bonhommeau, S., E. Chassot, B. Planque, E. Rivot, A.H. Knap, and O. Le Pape. 2008. Impact of climate on eel populations of the Northern Hemisphere. Marine Ecology Progress Series 373: 71–80.

Bonjean, F., and G.S.E. Lagerloef. 2002: Diagnostic model and analysis of the surface currents in the tropical Pacific Ocean. Journal of Physical Oceanography 32: 2938–2954.

Bossier, P. 1999. Authentication of seafood products by DNA patterns. Journal of Food Science 64(2): 189–193.

Briand, C., D. Fatin, E. Feunteun, and G. Fontenelle. 2005. Estimating the stock of glass eels in an estuary by mark-recapture experiments using vital dyes. Bulletin Français de la Pêche et de la Pisciculture 378–379: 23–46.

Castle, P.H.J. 1984. Notacanthiformes and Anguilliformes: Development. pp. 62–93. In (Eds.): Moser, H.G., W.J. Richards, D. M. Cohen, M. P. Fahay, A. W. Kendall, Jr., and S. L. Richardson. Ontogeny and systematics of fishes: based on an international symposium dedicated to the memory of Elbert Halvor Ahlstrom. IX + 766 pp.

Castle, P.H.J., and G.R. Williamson. 1974. On the validity of the fresh-water eel species *Anguilla ancestralis* Ege, from Celebes. Copeia 1974(2): 569–570.

Chang, S.-T., M.-F. Yeh, R.-T. Chen, C.-L. Tsai, K.-N. Shen, and C.-F. Tsai. 2008. A giant exotic speckled longfin eel (*Anguilla reinhardtii* Staindachner, 1867) captured from the Sun Moon Lake. Endemic Species Research (Taipei) 10(2): 59–64.

Chapela, M.J., C.G. Sotelo, R.I. Pérez-Martín, M.Á. Pardo, B. Pérez-Villareal, P. Gilardi, and J. Riese. Comparison of DNA extraction methods from muscle of canned tuna for species identification. Food Control 18: 1211–1215.

Chisnall, B.J. 2000. The Australian longfinned eel, *Anguilla reinhardtii*, in New Zealand. Conservation Advisory Science Notes No. 302. Department of Conservation, Wellington, New Zeeland. 16 pp.

CITES. 2006. Inclusion of *Anguilla anguilla* in Appendix II in Accordance with Article II, Paragraph 2 (A). Proposal for CITES Consultation Process. Twenty-second meeting of the Animals Committee Lima (Peru). AC22 Inf. 7. 38 pp.

CITES. 2007. Notification to the parties. No. 2007/022. Geneva, 26 July 2007. Concerning: Amendments to Appendices I and II of the Convention. 8 pp.

CITES. 2008. Convention on international trade in endangered species of wild fauna and flora. Appendices I, II and III, valid from 1 July 2008. 47 pp.

Comparini, A., and M. Schoth. 1982. Comparison of electrophoretic and meristic characters of 0-group larvae from the Sargasso Sea. Helgoländer Meeresuntersuchungen 35: 289–299.

Costa, F.O., and G.R. Carvalho. 2007. The Barcode of Life Initiative: synopsis and prospective societal impacts of DNA barcoding of Fish. Genomics, Society and Policy 3(2): 29–40.

Cracraft, J. 1983. Species concepts and speciation analysis. Current Ornithology 1:159–187.

Creutzberg, F. 1958. Use of Tidal Streams by Migrating Elvers (*Anguilla vulgaris* Turt.). Nature 181: 857–858.

Daemen, E., T. Cross, F. Ollevier, and F.A.M. Volckaert. 2001. Analysis of the genetic structure of european eel (*Anguilla anguilla*) using microsatellite DNA and mtDNA markers. Marine Biology 139: 755–764.

Dannewitz, J., G.E. Maes, L. Johansson, H. Wickström, F.A.M. Volckaert, and T. Järvi. 2005. Panmixia in the European eel: a matter of time. Proceedings of the Royal Society of London. Series B, Biological sciences. 272: 1129–1137.

Daverat, F., K.E. Limburg, I. Thibault, J.C. Shiao, J.J. Dodson, F. Caron, W.-N. Tzeng, Y. Iisuka, and H. Wickström. 2006. Phenotypic plasticity of habitat use by three temperate eel species *Anguilla anguilla*, *A. japonica* and *A. rostrata*. Marine Ecology Progress Series 308: 231–241.

De Silva, S.S., R.M. Gunasekera, and R.O. Collins. 2002. Some morphometric and biochemical features of ready-to-migrate silver and pre-migratory yellow stages of the shortfin eel of south-eastern Australian waters. Journal of Fish Biology 61: 915–928.

Deeds, J., H. Yancy, F. Fry, H. Granade1, R. Hanner, and P. Hebert. 2007. FDA Assessment of DNA Bar-Coding for Species Identification of Fish. Part Two: Recent Food Safety Case Studies. Abstract from presentation given at the Seafood Science and Technology Society of the Americas' 31st Annual SST Conference in Punta Cana, Dominican Republic, November 5–9, 2007. (http://sst.ifas.ufl.edu/31stann/abstracts/g%20Deeds%20SST%202007_edit.pdf; retrieved 19 Oct 2008)

Dekker, W. 1998. Long-term trends in the glass eels immigrating at Den Oever, The Netherlands. Bulletin de la Pêche et de Pisciculture, Conseil Superieur de la Pêche, Paris (France) 349, 199–214.

Dekker, W. 2000. A Procrustean assessment of the European eel stock. ICES Journal of Marine Science 57: 938–947.

Dekker, W. 2003. Did lack of spawners cause the collapse of the European eel, *Anguilla anguilla*? Fisheries Management and Ecology, 10: 365–376.

Dekker, W., M. Pawson, and H. Wickström. 2007. Is there more to eels than slime? An introduction to papers presented at the ICES Theme Session in September 2006. ICES Journal of Marine Science: Journal du Conseil Advance Access published online on August 22, 2007. 2 pp.

Dijkstra, L.H., and D.J. Jellyman. 1999. Is the subspecies classification of the freshwater eels *Anguilla australis australis* Richardson and *A. a. schmidtii* Phillipps still valid? Marine and Freshwater Research 50(3) 261–263.

Efron, B, and R. Tibshirani. 1986. Bootstrap methods for standard errors, confidence intervals, and other measures of statistical accuracy. Statistical Science 1: 54–77.

Ege, V. 1939. A revision of the genus *Anguilla* Shaw. A systematic, phylogenetic and geographical study. Dana-Report No. 16. 256 pp. + VI pls.

Eschmeyer, W.N. (Ed.). 1998. Catalog of fishes. Special Publication, California Academy of Sciences, San Francisco. 3 vols. 2905 pp.

Eurostat. 2007 (February 2007). Agriculture and fisheries. Fisheries. Catches in the north-east Atlantic. "Region R27 – North-east Atlantic". (http://epp.eurostat.ec.europa.eu; retrieved 18 Oct 2008)

Evans, H. 2008. Fines for pair who netted eels illegally near Bosherston. The Environment Agency News. (http://www.environment-agency.gov.uk/news/2142745; retrieved 10 November 2008)

Fahay, M. 2007. Early Stages of Fishes in the Western North Atlantic Ocean (Davis Strait, Southern Greenland and Flemish Cap to Cape Hatteras). Volume 1: Acipenseriformes through Syngnathiformes. NAFO, Dartmouth, Canada. pp. I-LIV + 1-931. (on-line version available at http://www.nafo.int/Publications/frames/fahay.html)

FAO. 2005 (c2004–2008). Cultured Aquatic Species Information Programme – *Anguilla anguilla*. Text compiled by Bergamini, N. In FAO Fisheries and Aquaculture Department [online]. Rome. Updated 7 Feb 2005. (http://www.fao.org/fishery/culturedspecies/Anguilla_anguilla; retrieved 18 Oct 2008).

FAO. 2006. Fishery Statistical Collections. Global Capture Production (online query). FIGIS. Global Capture Production 1950–2006. (http://www.fao.org/fishery/statistics/global-capture-production/en; retrieved 23 Sep 2008)

FishBase. 2008. In (Eds.) Froese, R., and D. Pauly. 2008. FishBase. World Wide Web electronic publication. www.fishbase.org, version (07/2008).

Frankowski, J., S. Jennerich, T. Schaarschmidt, C. Ubl, K. Jürss, and R. Bastrop. 2008. Validation of the occurrence of the American eel *Anguilla rostrata* (Le Sueur, 1817) in free-draining European inland. Biological

invasions (Springer, Netherlands) "Online First". (published on-line 8 August 2008; retrieved: 23 September 2008). 9 pp.

Freyhof, J. and M. Kottelat. 2008. *Anguilla anguilla*. In: IUCN 2008. 2008 IUCN Red List of Threatened Species. (http://www.iucnredlist.org/details/60344; retrieved 10 November 2008).

Fricke, R. 1999. Fishes of the Macarene Islands (Réunion, Mauritius, Rodriguez). An annotated checklist, with descriptions of new species. Koeltz Scientific Books, Königstein. 759 pp.

Frost, H. 2001. A socioeconomic cost-benefit analysis of the use of glass eel. Rapport – Statens Jordbrugs- og Fiskerioekonomiske Institut (Denmark). 1395–5705, no. 118. 61 pp.

Funk, D.J., and K.E. Omland. 2003. Species-level paraphyly and polyphyly. Frequency, causes, and consequences, with insights from animal mitochondrial DNA. Annual Review of Ecology, Evolution, and Systematics 34: 397–423.

Gainey, P. 2007. Bridgwater fisherman fined after being found guilty of offences. The Environment Agency News. (http://www.environment-agency.gov.uk/news/1909743; retrieved 10 November 2008)

Gainey, P. 2008. Elver fisherman fined for flouting byelaws. The Environment Agency News. (http://www.environment-agency.gov.uk/news/2137752; retrieved 10 November 2008)

Gascuel, D. 1986. Flow-carried and active swimming migration of the glass eel (*Anguilla anguilla*) in the tidal area of a small estuary on the French Atlantic coast. Helgoländer Meeresuntersuchungen 40: 321–326.

Gooley, G.J. 1997. Eels. pp. 101–107. In (Ed.) Hyde, K. The New Rural Industries. A handbook for Farmers and Investors. Australian Government, Rural Industries Research and Development Corporation. 570 pp.

Goudswaard, K.P.C., F. Witte, L.J. Chapman. 2002. Decline of the African lungfish (*Protopterus aethiopicus*) in LakeVictoria (East Africa). African Journal of Ecology 40: 42–52.

Greenwood. P.H., D.E. Rosen, S.H. Weitzman, and G.S. Myers. 1966. Phyletic studies of teleostean fishes, with a provisional classification of living forms. Bulletin of the American Museum of Natural History 131: 339–456.

Grey, M., A.-M. Blais, B. Hunt, and A.C.J. Vincent. 2006. The USA's international trade in fish leather, from a conservation perspective. Environmental Conservation 33 (2): 100–108.

Han Y.-S., C.-H. Yu, H.-T. Yu, C.-W. Chang, I-C. Liao, and W.-N. Tzeng. 2002. The exotic American eel in Taiwan: ecological implications. Journal of Fish Biology 60: 1608–1612.

Hayward, C.J., M. Iwashita, K. Ogawa, and I. Ernst. 2001. Global spread of the eel parasite *Gyrodactylus anguillae* (Monogenea). Biological Invasions 3: 417–424.

Herzberg, M. R. Fisher, and A. Titze. 2002. Conflicting results obtained by RAPD-PCR and large-subunit rDNA sequences in determining and comparing yeast strains isolated from flowers: a comparison of two methods. International Journal of Systematic and Evolutionary Microbiology 52: 1423–1433.

Huang, J.-P., Y.-S. Han, and W.-N. Tzeng. 2001. Species identification of anguillid eels by Polymerase Chain Reaction/Restriction Fragment Length Polymorphism analysis of the Gonadotropin II-β subunit gene. Acta Zoologica Taiwanica 12(2): 41–49.

Hubalkova, Z., P. Kralik, B. Tremlova, and E. Rencova. 2007. Methods of gadoid fish species identification in food and their economic impact in the Czech Republic: a review. Veterinarni Medicina 52(7): 273–292.

Hubert, N., R. Hanner, E. Holm, N.E. Mandrak, E. Taylor, M. Burridge, D. Watkinson, P. Dumont, A. Curry, P. Bentzen, J. Zhang, A. J. April, and L. Bernatchez. 2008. Identifying Canadian Freshwater Fishes through DNA Barcodes. PloS ONE 3(6): 1–45.

Hwang, D.-F., H.-C. Je, Y.-W. Hsieh, and C.Y. Shiau. 2004. Applying DNA Techniques to the Identification of the Species of Dressed Toasted Eel Products. Journal of Agricultural and Food Chemistry 52: 5972-5977.

ICES. 2000. Report of the EIFAC/ICES Working Group on Eels, Silkeborg, Denmark, 20–24 September 1999. ICES C.M. 2000/ACFM:6.

ICES. 2000. Report of the EIFAC/ICES Working Group on Eels, Silkeborg, Denmark, 20–24 September 1999. ICES C.M. 2000/ACFM:6.

ICES. 2005. Report of the EIFAC/ICES Working Group on Eels. ICES CM 2005/I:01, Ref. G, ACFM. 186 pp.

ICES. 2008a. Report of the Joint EIFAC/ICES Working Group on Eels (WGEEL), 3–9 September 2008, Leuven, Belgium. ICES CM 2008/ ACOM:15. 212 pp.

ICES. 2008b. European eel. Advice 2008, Book 9. 13 October 2008. pp 124–129.

Inoue, J.G., M. Miya, J. Aoyama, S. Ishikawa, K. Tsukamoto, and M. Nishida. 2001. Complete mitochondrial DNA sequence of the Japanese eel *Anguilla japonica*. Fisheries Science 67: 118–125.

Ishikawa, S., J. Aoyama, K. Tsukamoto, and M. Nishida. 2001. Population structure of the Japanese eel *Anguilla japonica* as examined by mitochondrial DNA sequencing. Fisheries Science 67: 246–253.

Ishikawa, S., K. Tsukamoto, and M. Nishida. 2004. Genetic evidence for multiple geographic populations of the giant mottled eel *Anguilla marmorata* in the Pacific and Indian oceans. Ichthyological Research 51: 343–353.

Itoi, S., M. Nakaya, G. Kaneko, H. Kondo, K. Sezaki, and S. Watabe. 2005. Rapid identification of eels *Anguilla japonica* and *Anguilla anguilla* by polymerase chain reaction with single nucleotide polymorphism-based specific probes. Fisheries Science. 71: 1356–1364.

Jamandre, B.W.D., K.N. Shen, A.V. Yambot, and W.N. Tzeng. 2007. Molecular phylogeny of Philippine freshwater eels *Anguilla* spp. (Actinopterygii: Anguilliformes: Anguillidae) inferred from mitochondrial DNA. The Raffles Bulletin of Zoology 14: 51–59.

James, S.A., and A.Y. Suzumoto. 2006. Nonnative occurrence of *Anguilla marmorata* in Hawai'i: identification using morphological and molecular characters. Bishop Museum Occasional Papers 87: 55–61.

Jeffs, A. 2003. Assessment of the potential for Aquaculture development in Northland. National of water & Atmospheric Research Ltd, Client Report: AKL2003-012. 245 pp.

Jegstrup, I.M., and P. Rosenkild. 2003. Regulation of post-larval development in the European eel: thyroid hormone level, progress of pigmentation and changes in behaviour. Journal of Fish Biology 63: 168–175.

Jellyman, D.J. 1979. Upstream migration of glass-eels (*Anguilla* spp.) in the Waikato river. New Zealand Journal of Marine & Freshwater Research 13(1): 13–22.

Jellyman, D.J. 2007. Status of New Zealand fresh-water eel stocks and management initiatives. ICES Journal of Marine Science 64: 1379–1386.

Jellyman, DJ. 1987. Review of the marine life history of Australasian temperate species of *Anguilla*. American Fisheries Society Symposium 1: 276–285.

Jenkins, A.P. 2003. A preliminary investigation of Priority Ichthyofaunal Areas for Assessing Representation in Fiji's Network of Forest Reserves. Technical Report to the Wildlife Conservation Society, October 2003. Wetlands International–Oceania, Canberra. 41 pp.

Jespersen, P. 1942. Indo-Pacific leptocephali of the genus *Anguilla*. Dana-Report No. 22. 128 pp. + IV pls.

Johnson, E.S., F. Bonjean, G.S.E. Lagerloef, J.T. Gunn, and G.T. Mitchum, 2007: Validation and Error Analysis of OSCAR Sea Surface Currents. Journal of Atmospheric and Oceanic Technology 24: 688–701.

Kessing B., H. Croom, A. Martin, C. McIntosh, M.W. Owen, S. Palumbi. 1989. The simple fool's guide to PCR. University of Hawaii, Honolulu. (Published and distributed by the authors.)

Kettle, A.J. and K. Haines. How does the European eel (*Anguilla anguilla*) retain its population structure during its larval migration across the North Atlantic Ocean? Canadian Journal of Fisheries and Aquatic Sciences 63: 90–106.

Kettle, A.J., D. Heinrich, J.H. Barrett, N. Benecke, and A. Locker. 2008. Past distributions of the European freshwater eel from archaeological and palaeontological evidence. Quaternary Science Reviews 27: 1309–1334.

Kirk, R.S. 2003. The impact of *Anguillicola crassus* on European eels. Fisheries Management and Ecology 10: 385–394.

Kottelat, M. 2001. Fishes of Laos. WHT Publications (Pte) Ltd., Colombo, Sri Lanka. 198 pp.

Kuroki, M., J. Aoyama, M.J. Miller, S. Wouthuyzen, T. Arai, and K. Tsukamoto. 2006. Contrasting patterns of growth and migration of tropical anguillid leptocephali in the western Pacific and Indonesian Seas. Marine Ecology Progress Series 309: 233–246.

Laboute, P., and R. Grandperrin. 2000. Poissons de Nouvelle-Calédonie. Editions Catherine Ledru, Nouméa, New Caledonia. 520 pp.

Lecomte-Finiger, R., A. Lo-Yat, L. Yan. 2000. First record of *Anguilla* glass eels from an atoll of French Polynesia: Rangiroa, Tuamoto Archpelago. Atoll Research Bulletin No. 486: 1 Fig. + 6 pp.

Lee, S.C., S.C.M. Tsoi, H.L. Cheng, and J.T. Chang. 1997. Identification of *Anguilla japonica* and *A. marmorata* elvers by allozyme electrophoresis. Journal of Fish Biology 51, 208–210.

Lehmann, D., H. Hettwer, and H. Taraschewski. 2000. RAPD-PCR investigations of systematic relationships among four species of eels (Teleostei: Anguillidae), particularly *Anguilla anguilla* and *A. rostrata*. Marine Biology 137: 195–204.

Liang, J., D. Li, and L. Lu. 2005. Microsatellite variation between Japanese eel (*Anguilla japonica*) and European eel (*Anguilla anguilla*). Chinese Journal of Oceanology and Limnology 23(4): 448–454.

Lin, Y.-S., C.-H. Tzeng, and J.-K. Hwang. 2005. Reassessment of morphological characteristics in freshwater eels (genus *Anguilla*, Anguillidae) shows congruence with molecular phylogeny estimates. Zoologica Scripta 34(3): 225–234.

Lin, Y.-S., Y.-P. Poh, and C.-S. Tzeng. 2001. A phylogeny of freshwater eels inferred from mitochondrial genes. Molecular Phylogenetics and Evolution 20(2): 252–261.

Lin, Y.-S., Y.-P. Poh, S.-M. Lin, and C.S. Tzeng. 2002. Molecular techniques to identify freshwater eels: RFLP Analyses of PCR-amplified DNA fragments and allele-specific PCR from mitochondrial DNA. Zoological Studies (Taipei) 41(4): 421–430.

Liu, Z.J., and J.F. Cordes. 2004. DNA marker technologies and their applications in aquaculture genetics. Aquaculture 238: 1–37.

López, J.A., M.W. Westneat, and R. Hanel. 2007. The phylogenetic affinities of the mysterious anguilliform genera *Coloconger* and *Thalassenchelys* as supported by mtDNA sequences. Copeia 2007(4): 959–966.

Lunt, D.J., P.J. Valdes, A. Haywood, I.C. Rutt. 2008. Closure of the Panama Seaway during the Pliocene: implications for climate and Northern Hemisphere glaciation. Climate Dynamics 30(1): 1–18.

Lunt, D.J., G.L. Foster, A.M. Haywood, and E.J. Stone. 2008. Late Pliocene Greenland glaciation controlled by a decline in atmospheric CO2 levels. Nature 454 (28 August 2008): 1102–1105.

Macintosh, D.J. E.C. Ashton, and V. Tansakul. 2002. Utilisation and knowledge of biodiversity in the Ranong Biosphere Reserve, Thailand. Integrated Tropical Coastal Zone Management, Asian Institute of Technology, Thailand. Monograph No. 7. 30pp.

Mackie I., Craig A., Etienne M., Jerome M., Fleurence J., Jessen F., 2000. Species identification of smoked and gravad fish products by sodium dodecylsulphate polyacrylamide gel electrophoresis, urea isoelectric focusing and native isoelectric focusing: a collaborative study. Food Chemistry 71: 1–7.

Maes, G.E., J.M. Pujolar, B. Hellemans, and F.A.M. Volckaert. 2006. Evidence for isolation by time in the European eel (*Anguilla anguilla* L.). Molecular Ecology 15: 2095–2107.

Mank, J.E., and J.C. Avise. 2003. Microsatellite variation and differentiation in North Atlantic eels. Journal of Heredity 94(4): 310–314.

Marui,, M., T. Arai, M.J. Miller, D.J. Jellyman, and K. Tsukamoto. 2001. Comparison of early life history between New Zealand temperate eels and Pacific tropical eels revealed by otolith microstructure and microchemistry. Marine Ecology Progress Series 213: 273–284.

Matsui, I. 1984. Theory and Practice of Eel Culture. (translation by A Gopal). CRC Press. 192 pp.

McCosker, J., R. Bustamante, and G. Wellington. 2003. The freshwater eel, *Anguilla marmorata*, discovered in Galápagos. Noticias de Galápagos 62: 2–6.

McGowan, M.F. and F.H. Berry. 1984. Clupeiformes: development and relationships. pp. 108–126. In (Eds.): Moser, H.G., W.J. Richards, D. M. Cohen, M. P. Fahay, A. W. Kendall, Jr., and S. L. Richardson. Ontogeny and systematics of fishes: based on an international symposium dedicated to the memory of Elbert Halvor Ahlstrom. IX + 766 pp.

McKinnon, L.J. 2006. A review of eel biology: knowledge and gaps. Audentes Investments Pty. Ltd., Point Lonsdale VIC, Australia. 39 pp.

Meyer, C.P., and G. Paulay. 2005. DNA barcoding: error rates based on comprehensive sampling. PLoS Biology 3(12): 2229–2238.

Miller, M.J., and J.D. McCleave. 1994. Species assemblages of leptocephali in the Subtropical Convergence Zone of the Sargasso Sea. Journal of Marine Research 52: 743–772.

Miller, M.J., and K. Tsukamoto. 2006. Studies on eels and leptocephali in southeast Asia: a new research frontier. Coastal Marine Science 30(1): 283–292.

Miller, M.J., J. Aoyama, N. Mochioka, T. Otake, P.H.J. Castle, G. Minagawa, T. Inagaki, and K. Tsukamoto. 2006. Geographic variation in the assemblages of leptocephali in the western South Pacific. Deep-Sea Research Part I: Oceanographic Research Papers 53: 776–794.

Miller, M.J., J. Aoyama, N. Mochioka, T. Otake, P.H.J. Castle, G. Minagawa, T. Inagaki, and K. Tsukamoto. 2006. Geographic variation in the assemblages of leptocephali in the western South Pacific. Deep-Sea Research I 53: 776–794.

Minegishi, Y., J. Aoyama, and K. Tsukamoto. 2008. Multiple population structure of the giant mottled eel, *Anguilla marmorata*. Molecular Ecology 17: 3109–3122.

Minegishi, Y., J. Aoyama, J.G. Inoue, M. Miya, M. Nishida, and K. Tsukamoto. 2005. Molecular phylogeny and evolution of the freshwater eels genus *Anguilla* based on the whole mitochondrial genome sequences. Molecular Phylogenetics and Evolution 34: 134–146.

Mochioka, N. 1996. Morphology and growth of Japanese eel larvae. pp. 22–32. In: Tabeta, O. (Editor). Early life history and prospects of seed production of Japanese eel *Anguilla japonica*. Kouseisha-Kouseikaku, Tokyo. (In Japanese. Original not seen, as cited in: Tanaka, H., H. Kagawa, H. Ohta. 2001. Production of leptocephali of Japanese eel (*Anguilla japonica*) in captivity. Aquaculture 201: 51–60.)

Modayil, M.J., R. Sathiadhas, and G. Gopakumar. 2008. India. pp. 145–188. In (Eds.) Lovatelli, A., M.J. Phillips, J.R. Arthur. 2008. The future of mariculture: a regional approach for responsible development in the Asia-Pacific region. Food and Agricultural Organization of the United Nations, Rome. xii + 325 pp.

Nieddu, M., G. Pichiri, P. Coni, S. Salvadori, A.M. Deiana, and R. Mezzanotte. 1998. A comparative analysis of European and American eel (*Anguilla anguilla* and *Anguilla rostrata*) genomic DNA: 5S rDNA polymorphism permits the distinction between the two populations. Genome 41: 728–732.

O' Sullivan, M., M. Cross, G. Dahle, and E. Gosling. 2007. ToR(c): identify and provide recommendations for the optimal extraction and storage of DNA

from fish for molecular based studies. pp. 31–34. In: ICES. 2007. Report of the working group on the application of genetics in fisheries and mariculture (WGAGFM). 19–23 March 2007. Ispra, Italy. 70 pp.

Obermiller, L.E., and E. Pfeiler. 2003. Phylogenetic relationships of elopomorph fishes inferred from mitochondrial ribosomal DNA sequences. Molecular Phylogenetics and Evolution 26: 202–214.

Okamura, A., H. Zhang, N. Mikawa, A. Kotake, Y. Yamada, T. Utoh, N. Horie, S. Tanaka, H.P. Oka, and K. Tsukamoto. 2008. Decline in non-native freshwater eels in Japan: ecology and future perspectives. Environmental Biology of Fishes 81: 347–358..

Okamura, A., H. Zhang, T. Utoh, A. Akazawa, Y. Yamada, N. Horie, N. Mikawa, S. Tanaka, and H.P. Oka. 2004. Artificial hybrid between *Anguilla anguilla* and *A. japonica*. Journal of Fish Biology 64: 1450–1454.

Okamura, A., H. Zhang, Y. Yamada, T. Uto, N. Mikawa, N. Horie, S. Tanaka, and T. Motonobu. 2001. Identification of two eel species, *Anguilla japonica* and *A. anguilla* by discriminant function analysis. Nippon Suisan Gakkaishi. 67(6): 1056–1060. (In Japanese, with English summary, table, and figure texts.)

Ottolenghi, F., C. Silvestri, P. Giordano, A. Lovatelli, and M.B. New. 2004. Capture-based aquaculture. The fattening of eels, groupers, tunas and yellowtails. Food and Agricultural Organization of the United Nations, Rome. xxiv + 308 pp.

Parson, W., K. Pegoraro, H. Niederstätter, M. Föger, M. Steinlechner. 2000. Species identification by means of the cytochrome b gene. International Journal of Legal Medicine 114: 23–28.

Pichiri, G., M. Nieddu, S. Manconi, C. Casu, P. Coni, S. Salvadori, and R. Mezzanotte. 2006. Isolation and characterization of two different 5S rDNA in *Anguilla anguilla* and in *Anguilla rostrata*: possible markers of evolutionary divergence. Molecular Ecology Notes 6: 638–641.

Poyser, E. 2008. Boat used in illegal elver fishing to be destroyed. The Environment Agency News. (http://www.environment-agency.gov.uk/news/2142031; retrieved 10 November 2008)

Queiroz, K. de. 1998. The general lineage concept of species, species criteria, and the process of speciation. A conceptual unification and terminological recommendations. pp 57–75. In: Howard, D.J., and S.H. Berlocher. (Eds.). Endless Forms: Species and Speciation. Oxford University Press, Oxford. 470 pp.

Rahman, A.K.A., 1989. Freshwater fishes of Bangladesh. Zoological Society of Bangladesh. Department of Zoology, University of Dhaka. 364 p.

Rasmussen, R.S., and M.T. Morrissey. 2008. DNA-based methods for the identification of commercial fish and seafood species. Comprehensive reviews in food sciences and food safety 7: 280–295.

Ratnasingham, S., and P.D.N. Hebert. 2007. BOLD: The Barcode Of Life Data system. Molecular Ecology Notes 7: 355–364.

Richards, W.J. 1984. Elopiformes: Development. pp. 60–61. In (Eds.): Moser, H.G., W.J. Richards, D. M. Cohen, M. P. Fahay, A. W. Kendall, Jr., and S. L. Richardson. Ontogeny and systematics of fishes: based on an international symposium dedicated to the memory of Elbert Halvor Ahlstrom. IX + 766 pp.

Ringuet, S., F. Muto, and C. Raymakers. 2002. Eels, their harvest and trade in Europe and Asia. TRAFFIC Bulletin 19(2): 2–27.

Robinet, T., E. Réveillac, M. Kuroki, J. Aoyama, K. Tsukamoto, M.W. Rabenevanana, P. Valade, P.-A. Gagnaire, P. Berrebi, E. Feunteun. 2008. New clues for freshwater eels (*Anguilla* spp.) migration routes to eastern Madagascar and surrounding islands. Marine Biology 154: 453–463.

Robinet, T., R. Lecomte-Finiger, K. Escoubeyrou, E. Feunteun. 2003. Tropical eels *Anguilla* spp. recruiting to Réunion Island in the Indian Ocean: taxonomy, patterns of recruitment and early life histories. Marine Ecology Progress Series 259: 263–272.

Rock, J., F.O. Costa, D.I. Walker, A.W. North, W.F. Hutchinson, and G.R. Carvalho. 2008. DNA barcodes of fish of the Scotia Sea, Antarctica indicate priority groups for taxonomic and systematics focus. Antarctic Science 20(3), 253–262.

Russell, I.A., and N.D. Impson. 2006. Aquatic systems in and adjacent to Agulhas National Park with particular reference to the fish fauna. Koedoe 49(2): 45–57.

Sage, A. 2007. Eel poachers put 'white gold' on critical list. The Times. December 13, 2007) (http://www.timesonline.co.uk/tol/life_and_style/food_and_drink/article3042597.ece; retrieved 06 November 2008)

Santella, R.M., and S.E. Hankinson. Biosampling methods. pp. 53–62. In: (Eds.) Rebbeck, T.R., C.B. Ambrosone, P.G. Shields. 2008. Molecular epidemiology. Informa Health Care. 320 pp.

Schmidt, J. 1922. The breeding places of the eel. Philosophical Transactions of the Royal Society of London. Series B, Containing Papers of a Biological Character 211: 179–208.

Schneider, M.F., V.A. Buramuge, L. Aliasse, and F. Serfontein. 2005. Checklist of Vertebrates of Mozambique. Universidade Eduardo Mondlane Faculdade de Agronomia e Engenharia Florestal Departamento de Engenharia Florestal Maputo, Moçambique. 228 pp.

Schwartz, J. 2008. Fish tale has DNA hook: students find bad labels. The New York Times, 22 August 2008, p. A1.

Scott, L.E.P., P.H. skelton, A.J. Booth, L. Verheust, R. Harris, and J. Dooley. 2006. Atlas of the southern African freshwater fishes. The South African Institute for Aquatic Biodiversity Grahamstown. IX + 303 pp + CD-ROM.

Sevilla, R.G., A. Diez, M. Norén, O. Mouchel, M. Jérôme, V. Verrez-Bagnis, H. Van Pelt, L. Favre-Krey, G. Krey, The Fishtrace Consortium, and J.M. Bautista. 2007. Primers and polymerase chain reaction conditions for DNA barcoding teleost fish based on the mitochondrial cytochrome b and nuclear rhodopsin genes. Molecular Ecology Notes 7: 730–734

Sezaki, K., S. Itoi, and S. Watabe. 2006. A simple method to distinguish two commercially valuable eel species in Japan *Anguilla japonica* and *A. anguilla* using polymerase chain reaction strategy with a species-specific primer. Fisheries Science 71: 414–421.

Shen, K.N., and W.N. Tzeng. 2007. Genetic differentiation among populations of the shortfinned eel *Anguilla australis* from East Australia and New Zealand. Journal of Fish Biology 70(Suppl. B): 177–190.

Shiao, J.-C., W.-N. Tzeng, A. Collins, D.J. Jellyman. 2001. Dispersal pattern of glass eel stage of *Anguilla australis* revealed by otolith growth increments. Marine Ecology Progress Series 219: 241–250.

Skelton, P.H. 1993. A Complete Guide to the Freshwater Fishes of Southern Africa. Halfway House: Southern Book Publishers (Pte) Ltd., South Africa. xiii + 388 pp.

Smith, D.G. 1999. Freshwater eels. pp 1630–1642. In: Carpenter, K.E., and V.H. Niem, (Eds.). 1999. FAO species identification guide for fishery purposes. The living marine resources of the Western Central Pacific. Volume 3. Batoid fishes, chimaeras and bony fishes part 1 (Elopidae to Linophrynidae). 1397–2068.

Smith, P.J., P.G. Benson, C. Stanger, B.L. Chisnall, and D.J. Jellyman. 2001. Genetic structure of New Zealand eels *Anguilla dieffenbachii* and *A. australis* with allozyme markers. Ecology of Freshwater Fish 10: 132–137.

Song, H., J.E. Buhay, M.F. Whiting, and K.A. Crandall. 2008. Many species in one: DNA barcoding overestimates the number of species when nuclear mitochondrial pseudogenes are coamplified. Proceedings of the National Academy of Sciences of the United States of America 105(36): 13486–13491.

Strehlow, B. 1996. Biometric studies on premetamorphic eel larvae of *Anguilla anguilla* (Anguilliformes: Anguillidae) in comparison with younger developmental stages of the species. Helgoländer Meeresuntersuchungen 50: 415–424.

Strid, P. 2008a. Fullt av illegala ålfällor – men myndigheterna gör ingenting. Miljöaktuellt. (http://miljoaktuellt.idg.se/2.1845/1.189660/fullt-av-illegala-alfallor--men-myndigheterna-gor-ingenting; retrieved 10 November 2008)

Strid, P. 2008b. Ännu en illegal ålfälla som myndigheterna struntat i. Miljöaktuellt. (http://miljoaktuellt.idg.se/2.1845/1.191408/annu-en-illegal-alfalla-som-myndigheterna-struntat-i; retrieved 10 november 2008)

Sugeha, H.Y., T. Arai, M.J. Miller, D. Limbong, K. Tsukamoto. 2001. Inshore migration of the tropical eels *Anguilla* spp. recruiting to the Poigar River estuary on north Sulawesi Island. Marine Ecology Progress Series 221: 233–243.

Svedäng, H., E. Neuman, E. and H. Wickström. 1996. Maturation pattern in female European eel, age and size at silver shortfin eel stage. Journal of Fish Biology 48: 342–351.

Talwar, P.K. and A.G. Jhingran, 1991. Inland fishes of India and adjacent countries. vol 1. A.A. Balkema, Rotterdam. 541 p.

Tanaka, H., H. Kagawa, and H. Ohta. 2001. Production of leptocephali of Japanese eel (*Anguilla japonica*) in captivity. Aquaculture 201: 51–60.

Taylor, W.R., and G.C. Van Dyke. 1985. Revised procedures for staining and clearing small fishes and other vertebrates for bone and cartilage study. Cybium 9(2): 107–119.

Teletchea, F., V. Laudet, and C. Hänni. 2005. Phylogeny of the Gadidae (*sensu* Svetovidov, 1948) based on their morphology and two mitochondrial genes. Molecular Phylogenetics and Evolution 38: 189–199.

Tesch, F.-W.. 2003. The eel. Blackwell. VII + 408 pp.

Thibault, I., J.J. Dodson, F. Caron, W.-N. Tzeng, Y. Iizuka, and J.-C. Shiao. 2007. Facultative catadromy in American eels: testing the conditional strategy hypothesis. Marine Ecology Progress Series 344: 219–229.

Tjakrawidjaja, A.H. 2001. Jenis-jenis ikan yang dilindungi perundang-undangan Indonesia. In M. Noerdjito and I. Maryanto (Eds.). Jenis-jenis hayati yang dilindungi perundang-undangan Indonesia, p.117–124. Bidang Zoologi (Museum Zoologicum Bogoriense) Puslit Biologi LIPI, The Nature Conservancy & USAID. 221 p. (Original not seen, as cited in: Rachmatika, I., R. Nasi, D. Sheil, and M. Wan. 2005. A first look at the fish species of the Middle Malinau. Taxonomy, ecology, vulnerability and importance. Center for International Forestry Research, Jakarta. 34 pp.)

Todd, P.R. 1980. Size and age of migrating New Zealand freswater eels (*Anguilla* spp.). New Zealand Journal of Marine & Freshwater Research 14(3): 283–293.

Trautner, J. 2006. Rapid identification of European (*Anguilla anguilla*) and North American (*Anguilla rostrata*) by polymerase chain reaction. Informationen aus der Fischereiforschung 53: 49–51.

Tseng, M.-C., C.A. Chen, H.-W. Kao, W.-N. Tzeng, and S.-C. Lee. 2001. Polymorphisms of GA/GT microsatellite loci from *Anguilla japonica*. Marine Biotechnology 3: 275–280.

Tsukamoto, K. 1992. Discovery of spawning area for the Japanese eel. Nature 356: 789–791.

Tsukamoto, K., and T. Arai. 2001. Facultative catadromy of the eel *Anguilla japonica* between freshwater and seawater habitats. Marine Ecology Progress Series 220: 266–276.

Tsukamoto, K., I. Nakai, I., and W.-V. Tesch. 1998. Do all freshwater eels migrate? Nature 396: 635–636.

Tsukamoto, K., J. Aoyama, and M.J. Miller. 2002. Migration, speciation, and the evolution of diadromy in anguillid eels. Can. J. Fish. Aquat. Sci. 59: 1989–1998.

Ward, R.D., T.S. Zemlak, B.H. Innes, P.R. Last1, and P.D.N. Hebert. 2005. DNA barcoding Australia's fish species. Philosophical Transactions of the Royal Society of London. Series B, Containing Papers of a Biological Character 360: 1847–1857.

Watanabe, S. 2001. Taxonomic study of the freshwater eels, the genus *Anguilla* Schrank 1798. Unpublished PhD thesis, University of Tokyo, Japan. (Reference not seen, as cited in Watanabe, S., J. Aoyama, and K. Tsukamoto. 2006. Confirmation of morphological differences between *Anguilla australis australis* and *A. australis schmidtii*. New Zealand Journal of Marine and Freshwater Research 40: 325–331.)

Watanabe, S., J. Aoyama, and K. Tsukamoto. 2006. Confirmation of morphological differences between *Anguilla australis australis* and *A. australis schmidtii*. New Zealand Journal of Marine and Freshwater Research 40: 325–331.

Watanabe, S., J. Aoyama, K. Tsukamoto. 2004a. Reexamination of Ege's (1939) use of taxonomic characters of the genus *Anguilla*. Bulletin of Marine Sciences 74(2): 337–351.

Watanabe, S., J. Aoyama, M. Nishida, and K. Tsukamoto. 2005. A molecular genetic evaluation of the taxonomy of eels of the genus *Anguilla* (Pisces: Anguilliformes). Bulletin of Marine Science 76(3): 675–690.

Watanabe, S., J. Aoyama, M. Nishida, and K. Tsukamoto. 2005. Evaluation of the population structure of *Anguilla bicolor bicolor* using total number of vertebrae and the mtDNA control region. Coastal Marin Science 29(2): 165–169.

Watanabe, S., J. Aoyama, M.J. Miller, S. Ishikawa, E. Feunteun, and K. Tsukamoto. 2008. Evidence of population structure in the giant mottled eel, *Anguilla marmorata*, using total number of vertebrae. Copeia(3): 680–688.

Watanabe, S., Y. Minegishi, T. Yoshinaga, J. Aoyama, and K. Tsukamoto. 2004b. A quick method for species identification of Japanese eel (*Anguilla japonica*) using real-time PCR: an onboard application for use during sampling surveys. Marine Biotechnology 6: 566–574.

Westin, L. 2003. Migration failure in stocked eels *Anguilla anguilla*. Marine Ecology Progress Series 254: 307–311.

Williamson, G.R., and J. Boëtius. 1993. The eels *Anguilla marmorata* and *A. japonica* in the Pearl River, China, and Hong Kong. Asian fisheries Science 6: 129–138.

Wirth, T. and L. Bernatches. 2003. Decline of North Atlantic eels: a fatal synergy? Proceedings of the Royal Society of London. Series B, Biological sciences. 270: 681–688.

Wolf, C., M. Burgener, P. Hübner, and J. Lüthy. 2000. PCR-RFLP analysis of mitochondrial DNA: differentiation of fish species. Lebensmittel-Wissenschaft und -Technologie 33: 144–150.

Wong, E.H.-K., and R.H. Hanner. 2008. DNA barcoding detects market substitution in North American seafood. Food Research International 41: 828–837.

Yamamoto, K. and K. Yamauchi. 1974. Sexual maturation of Japanese eel and production of eel larvae in the aquarium. Nature 251: 220–222.

Yancy, H.F., T.S. Zemlak, J.A. Mason, J.D. Washington, B.J. Tenge, N.-L.T. Nguyen, J.D. Barnett, D. James, W. Savary, W. Hill, M.M. Moore, F.S. Fry, S.C. Randolph, P.L. Rogers, and P.D.N. Hebert. Potential use of DNA barcodes in regulatory science: applications of the Regulatory Fish Encyclopedia. Journal of food protection 71(1): 210–217.

Zachos, J., M. Pagani, L. Sloan, E. Thomas, and K. Billups. 2001. Trends, Rhythms, and Aberrations in Global Climate 65 Ma to Present. Science 292 (27 April 2001): 686–693.

Zhang, H., N. Mikawa, Y. Yamada, N. Horie, A. Okamura, T. Utoh, S. Tanaka, and T. Motonobu. 1999. Foreign eel species in the natural waters of Japan detected by polymerase chain reaction of mitochondrial cytochrome b region. Fisheries Science 65: 684–686.

Zilberman, N, S Reikhav, G Hulata, M Ron. 2006. High-throughput genomic DNA extraction protocol from tilapia's fin tissue. Aquaculture 255: 597–599.

Appendix – Tables

Table 9. Frequency distribution of vertebral counts for freshwater eel species of the genus *Anguilla*. Data combined from Ege (1939, all species), Aoyama *et al.* (2000, *A. interioris* and *A. celebesensis*) and Watanabe *et al.* (2008, *A. marmorata*). Underlined frequencies indicate 99% confidence intervals for sample size 15, based on 10,000 bootstrap replicates.

	100	101	102	103	104	105	106	107	108	109	110	111	112	113	114	115	116	117	118	119	N	MEDIAN	AVERAGE
mossambica	8	53	123	182	106	39	4														515	103	102.89
celebesensis		11	34	80	66	21	6	1													219	103	103.34
obscura		5	28	144	239	153	36	2	1												608	104	104.03
interioris		1		2	7		2	2													14	104	104.36
borneensis				2	15	37	32	13	4												103	105	105.50
marmorata	2	2	7	83	298	545	600	348	91	28	7										2011	106	105.60
rostrata				1	8	45	184	275	222	96	31	3									865	107	107.25
reinhardti					1	6	36	111	157	92	10										413	108	107.77
bicolor				2	6	18	81	177	300	419	416	199	79	7	2	1					1707	109	109.05
bengalensis							1	8	19	39	49	58	40	21	4	2					241	111	110.51
australis									2	36	166	492	654	466	156	44	3				2019	112	111.99
dieffenbachi										1	5	70	191	235	100	16	2				620	113	112.66
megastoma									1	1	7	25	61	84	41	8	3				231	113	112.68
anguilla											1	17	89	352	719	865	500	192	36	4	2775	115	114.73
japonica													3	13	80	169	207	139	45	14	670	116	115.84

Table 10. Frequency distribution of prehaemal vertebral counts for freshwater eel species of the genus *Anguilla*. Data extracted from Ege (1939) and Aoyama *et al.* (2000). Underlined frequencies indicate 99% confidence intervals for sample size 15, based on 10,000 bootstrap replicates.

	37	38	39	40	41	42	43	44	45	46	47	48	N	MEDIAN	AVERAGE
celebesensis	6	49	109	43	12								219	39	39.03
interioris			4	4	6	1							15	40	40.27
mossambica			30	232	233	25							520	40	40.49
borneensis			5	40	55	4							104	41	40.56
bengalensis			4	64	136	39							243	41	40.86
marmorata			2	134	471	215	11						833	41	41.12
obscura				31	268	276	25						600	42	41.49
megastoma				3	77	122	16	2					220	42	41.71
reinhardti					7	173	178	19					377	43	42.55
rostrata					4	23	61	12	1				101	43	42.83
bicolor					5	120	291	142	23				581	43	43.10
japonica						30	183	214	48				475	44	43.59
dieffenbachi							40	199	130	3	1		373	44	44.27
anguilla								33	118	63	12		226	45	45.24
australis								16	146	360	190	20	732	46	46.07

Table 11. Frequency distribution of vertebrae in adults and myomere counts in leptocephalus larvae of the two freshwater eel species in the Atlantic Ocean – *Anguilla anguilla* and *A. rostrata*; data by Schmidt, published in Jespersen (1942).

	103	104	105	106	107	108	109	110	111	112	113	114	115	116	117	118	119	N	MEDIAN	AVERAGE
rostrata – vertebrae	1	8	45	184	275	222	96	31	3									865	107	107.25
rostrata – myomeres		1	6	18	51	101	68	34	7									286	108	108.17
anguilla – myomeres										1	20	65	139	142	77	25	3	472	116	115.58
anguilla – vertebrae								1	17	89	352	719	865	500	192	36	4	2775	115	114.73
japonica – vertebrae										3	13	80	169	207	139	45	14	670	116	115.84

Table 12. Frequency distribution of mouth size classes relative to head length (% of head length) for freshwater eel species of the genus *Anguilla* larger than 200 mm total length. Data from Ege (1939, all species) and Aoyama *et al.* (2000, *celebesensis* and *interioris*). Headline percentages refer to intervals, e.g. 18 = 18.00-18.99 with statistics based on midpoint, 18.5. Note the abrupt shift in the median of mouth sizes between mouths smaller than 27% of head length and mouths larger than 30% of head length on average. Compare with specimens smaller than 200 mm TL in Table 13 for each species respectively. Underlined frequencies indicate 99% confidence intervals for the median of sample size 15, based on 10,000 bootstrap replicates.

	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	N	MEDIAN	AVERAGE
anguilla	1	2	4	19	25	51	66	98	67	57	17	11	1		1																	420	25.5	25.33
australis			1	3	9	40	67	88	59	23	11	5	4																			310	25.5	25.46
japonica			1	6	8	19	29	43	31	21	16	4	1																			179	25.5	25.62
reinhardti			1	3	6	11	16	32	41	26	13	5	1																			155	26.5	26.04
rostrata					2	6	10	30	22	13	10	3	2																			98	26.5	26.23
bicolor				1	12	27	38	38	35	43	49	16	17	8	5	2																291	26.5	26.82
obscura								1	6	20	40	47	59	48	53	45	19	4	1	1												344	30.5	31.03
dieffenbachi											5	14	41	47	34	22	6															169	31.5	31.57
marmorata									1	2	7	16	46	90	64	46	10	5		1												288	31.5	31.85
bengalensis								1		2	4	3	8	14	29	27	26	28	11	5	5	1	1									165	33.5	33.74
borneensis																2		1														3	33.5	34.17
mossambica										1	1	5	3	1	5	2	5	13	11	6	4	1										58	35.5	34.66
celebesensis											1		2	4	5	3	3	1	1	6	2	2	3	1	2							36	35.5	35.64
megastoma																1	1	4	16	26	26	33	27	18	9	2	1					164	39.5	39.20
interioris																					2		1	1		1		1			1	7	41.5	42.36

Table 13. Frequency distribution of mouth size classes relative to head length (% of head length) for freshwater eel species of the genus *Anguilla* smaller than 200 mm total length. Data from Ege (1939). Headline percentages refer to intervals, e.g. 20 = 20.00-20.99 with statistics based on midpoint, 20.5. Compare with specimens larger than 200 mm total length in Table 12 for each species respectively.

	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	N	MEDIAN	AVERAGE
australis		8	12	28	29	27	14	5	1	2							126	24.5	24.56
bicolor	4	4	21	37	38	64	43	21	5	2			1			1	241	25.5	25.14
anguilla				1	2	6	5	1									15	25.5	25.70
obscura		1		5	7	12	11	13	14	3	1						67	26.5	26.62
bengalensis					2	8	11	6	8	5	1		1				42	27.5	27.33
mossambica						7	15	12	25	18	18	6		1			102	28.5	28.64
dieffenbachi						1	10	17	20	23	16	8	2				97	29.5	28.98
marmorata						3	4	10	27	33	57	27	12	3			176	30.5	30.00
megastoma							1	1	4	2	3	5	1		1		18	30.5	30.17
celebesensis						1	1	1				3	3	1	1		11	31.5	30.86

Table 14. Frequency distribution of predorsal length classes (without the head) relative to total length (% of total length) for freshwater eel species of the genus *Anguilla*. All life stages included, including glass eels. Data from Ege (1939). Headline percentages refer to intervals, e.g. 8 = 8.00-8.99 with statistics based on midpoint, 8.5. Underlined frequencies indicate 99% confidence intervals for the median of sample size 15, based on 10,000 bootstrap replicates.

	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	N	MEDIAN	AVERAGE
marmorata	2	40	159	150	71	30	4																				456	11.5	11.28
mossambica		4	24	35	40	24	33	26	10		2																198	12.5	13.13
bengalensis				4	31	73	53	27	13	1	1	2															205	13.5	14.12
interioris					1	2	2	2																			7	14.5	14.21
megastoma					7	28	79	46	13	1	1																175	14.5	14.71
borneensis							1	1		1																	3	15.5	15.83
dieffenbachi							1	20	77	107	51	9		1													266	17.5	17.32
celebesensis							3	8	8	4	7	7	4	1													42	17.5	17.60
japonica								8	37	79	54	16	3														197	17.5	17.71
reinhardti								1	10	44	53	35	10	2													155	18.5	18.46
anguilla								9	42	86	103	85	39	8	8	2											382	18.5	18.58
rostrata											4	11	44	17	20	3	1										100	20.5	21.01
obscura													1	14	42	125	114	73	33	4		3					409	24.5	24.28
bicolor															4	30	72	129	145	97	41	14	2	2			536	26.5	26.24
australis															1	8	24	47	77	76	99	73	30	9	2	1	447	27.5	27.74

Table 15. Frequency distribution of anodorsal length classes relative to total length (% of total length) for freshwater eel species of the genus *Anguilla*. All life stages included, including glass eels. Data from Ege (1939). Headline percentages refer to intervals, e.g. 8 = 8.00-8.99 with statistics based on midpoint, 8.5. Underlined frequencies indicate 99% confidence intervals for the median of sample size 15, based on 10,000 bootstrap replicates.

	–6	–5	-4	–3	–2	–1	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	N	MEDIAN	AVERAGE
bicolor	1		3	14	68	105	187	112	44	1																535	0.5	0.32
australis					9	9	93	145	126	54	9	1														446	1.5	1.78
obscura					1		3	18	94	167	102	23	3													411	3.5	3.53
celebesensis													3	7	12	11	7	2								42	8.5	8.93
rostrata													3	12	35	33	15	2								100	9.5	9.01
japonica												1	2	18	59	77	34	5	1							197	9.5	9.21
reinhardti														3	14	58	98	50	9	2						234	10.5	10.41
dieffenbachi														1	9	49	107	73	26	1						266	10.5	10.72
megastoma														1	3	10	64	80	18	1						177	11.5	11.06
anguilla													1	5	7	37	86	124	92	27	3					382	11.5	11.37
bengalensis														1	5	7	38	75	55	12	2					195	11.5	11.57
borneensis																	1	1		1						3	11.5	11.83
interioris																		1	3	2	1					7	12.5	12.93
mossambica																		3	34	64	53	30	14			198	13.5	14.08
marmorata																			1	10	57	149	178	66	4	465	16.5	16.02

Appendix – Distribution maps

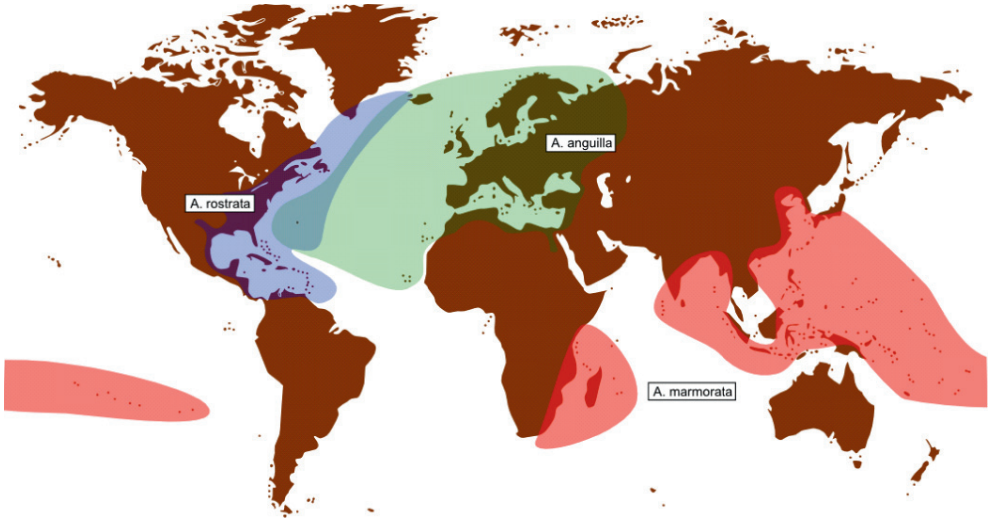


Figure 14. Approximate geographic distribution of (from the left) *Anguilla rostrata* (blue, western Atlantic Ocean), *A. anguilla* (green, eastern Atlantic Ocean), *A. marmorata* (red, from southwestern Indian Ocean to Paci c Ocean). Adapted from Watanabe *et al.* (2004); occurrence of *A. marmorata* in Bay of Bengal as suggested by Watanabe *et al.* (2008) and Minegishi *et al.* (2008) needs more research.

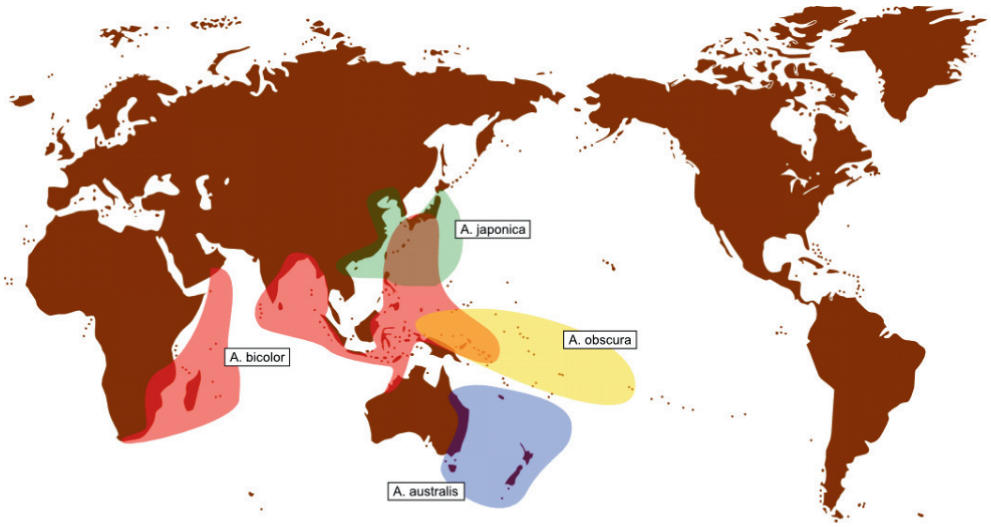


Figure 15. Approximate geographic distribution of (from the left) *Anguilla bicolor* (red, from western Indian Ocean to Western Paci c Ocean), *A. japonica* (green, northwestern Paci c Ocean), *A. obscura* (yellow, South Paci c Ocean), *A. australis* (blue, Australia and New Zealand). Adapted from Watanabe *et al.* (2004).

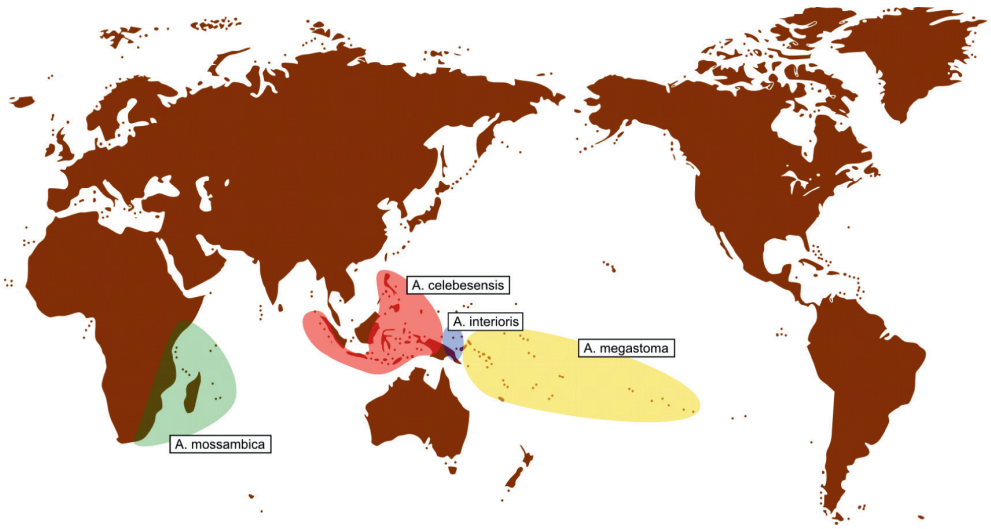


Figure 16. Approximate geographic distribution of (from the left) *Anguilla mossambica* (green, southwestern Indian Ocean), *A. celebesensis* (red, eastern Indian Ocean and western Paci c Ocean), *A. interioris* (blue, eastern Papua-New Guinea), *A. megastoma* (yellow, south Paci c Ocean). Adapted from Watanabe *et al.* (2004).

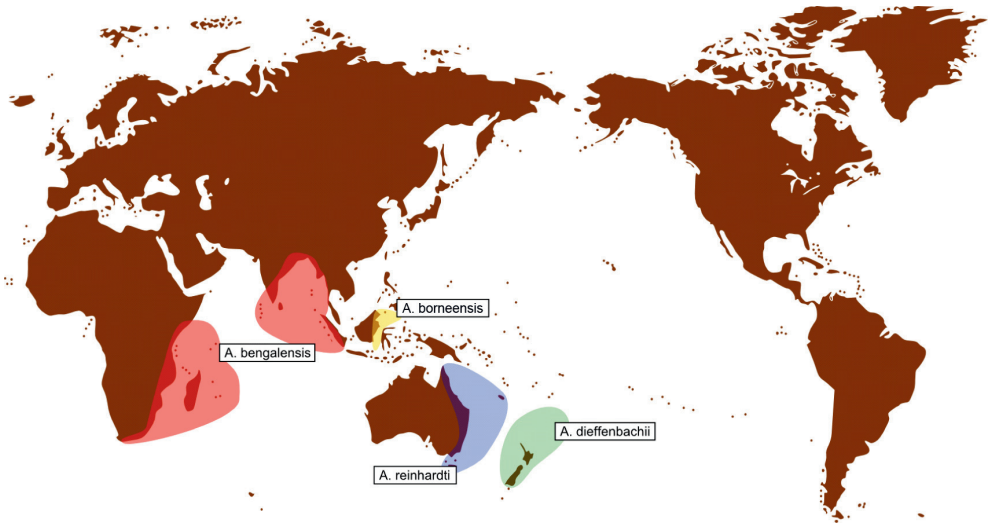


Figure 17. Approximate geographic distribution of (from the left) *Anguilla bengalensis* (western Atlantic Ocean), *A. borneensis* (eastern Borneo), *A. reinhardti* (eastern Australia and New Caledonia), and *A. dieffenbachi* (New Zeeland). Adapted from Watanabe *et al.* (2004).

Appendix – Species Photographs

Figure 18. *Anguilla anguilla* Glass eel. 70 mm TL. Photo: Håkan Wickström.

Figure 19. *Anguilla anguilla*. Left side lateral view. NRM 54768. Sweden, Kosterfjorden, close to Tjärnöviken, numerous places within 100 meters of all sides of Yttre Vattenholmen. 0.5–15m. Photo: Anders Silfvergrip.

Figure 20. *Anguilla anguilla*. Dorsal view. NRM 54768. Sweden, Kosterfjorden, close to Tjärnöviken, numerous places within 100 meters of all sides of Yttre Vattenholmen. 0.5–15m. Photo: Anders Silfvergrip.

Figure 21. *Anguilla anguilla* NRM 49648. Sweden, Flo Bay, south of the island of Saltö. 410 mm TL. Photo: Michael Norén.

Figure 22. *Anguilla anguilla*. Left side lateral view. NRM 31548. 500 mm TL. Sweden, Baltic Sea, Björkö Island, Arholma Island, Simpnäs, 1967. Photo: Anders Silfvergrip.

Figure 23. *Anguilla anguilla*. Dorsal view. NRM 31548. 500 mm TL. Sweden, Baltic Sea, Björkö Island, Arholma Island, Simpnäs, 1967. Photo: Anders Silfvergrip.

Figure 24. *Anguilla* australis. Right side lateral view (picture reversed). ZMUC P313473. New Zeeland, 1909. Photo: Anders Silfvergrip.

Figure 25. *Anguilla australis*. Dorsal view. ZMUC P313473. New Zeeland, 1909. Photo: Anders Silfvergrip.

Figure 26. *Anguilla bengalensis*. Silver eel. Sri Lanka 1987. Photo: Håkan Wickström.

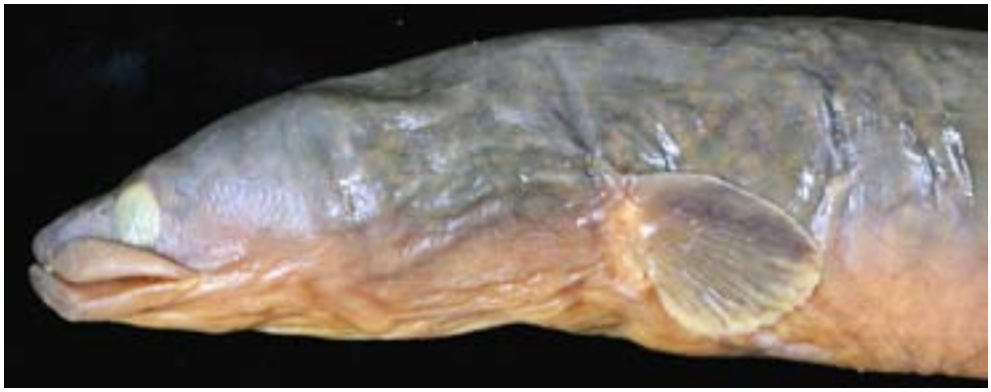


Figure 27. *Anguilla bengalensis*. NRM 40840. 422 mm TL. Myanmar, Kananmae Chaung, near Leldee village, by foot 45 min from Gwechaung village at km 18 on road Thandwe-Taunggok, 1998. Photo: Anders Silfvergrip.

Figure 28. *Anguilla bengalensis*. Left side lateral view. ZMUC P313453. Photo: Anders Silfvergrip.

Figure 29. *Anguilla bengalensis*. Dorsal view. ZMUC P313453. Photo: Anders Silfvergrip.

Figure 30. *Anguilla bicolor* (upper two) and A. bengalensis (lower). Sri Lanka, 1987.
Photo: Håkan Wickström.

Figure 31. *Anguilla bicolor* (left) and A. bengalensis (right). Sri Lanka, 1987.
Photo: Håkan Wickström.

Figure 32. *Anguilla bicolor*. Sri Lanka, 1987. Photo: Håkan Wickström.

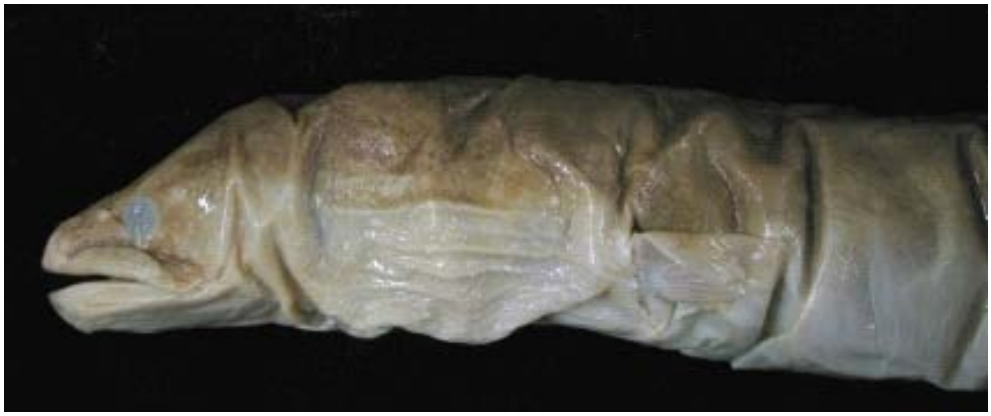


Figure 33. *Anguilla bicolor*. Left side lateral view. ZMUC P313475. Photo: Anders Silfvergrip

Figure 34. *Anguilla bicolor*. Dorsal view. ZMUC P313475. Photo: Anders Silfvergrip

Figure 35. *Anguilla bicolor*. Left side lateral view. NRM 13694. 422 mm TL. Sri Lanka, Malala Oya drainage, about 8 miles N of Hambantota, Badagiriya. Photo: Anders Silfvergrip.

Figure 36. *Anguilla bicolor*. Dorsal view. NRM 13694. 422 mm TL. Sri Lanka, Malala Oya drainage, about 8 miles N of Hambantota, Badagiriya. Photo: Anders Silfvergrip.

Figure 37. *Anguilla bicolor* Right side lateral view (picture reversed). NRM 14762. 360 mm TL. Sri Lanka, Kelani River, Colombo, river proper and connected freshwater lake, bought at Slave Island Market. Photo: Anders Silfvergrip.

Figure 38. *Anguilla bicolor.* Dorsal view. NRM 14762. 360 mm TL. Sri Lanka, Kelani River, Colombo, river proper and connected freshwater lake, bought at Slave Island Market.
Photo: Anders Silfvergrip.

Figure 39. *Anguilla celebesensis*. Left side lateral view. ZMUC P313484.
Photo: Anders Silfvergrip.

Figure 40. *Anguilla celebesensis*. Dorsal view. ZMUC P313484. Photo: Anders Silfvergrip.

Figure 41. *Anguilla japonica* together with *Silurus asotus*. 40 km SE Taipei, Ilan City, fish market near train station, 2002. Photo: Te Yu Liao.

Figure 42. *Anguilla japonica* together with *Silurus asotus*. 40 km SE Taipei, Ilan City, fish market near train station, 2002. Photo: Te Yu Liao.

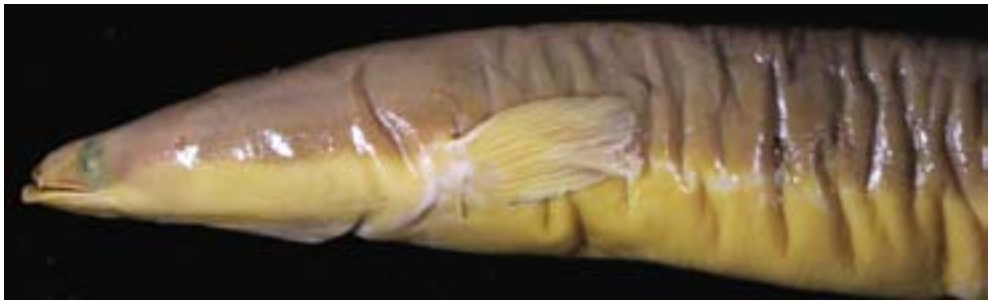


Figure 43. *Anguilla japonica*. Left side lateral view. NRM 36617. China, Guangzhou [Canton], 1879. Photo: Anders Silfvergrip.

Figure 44. *Anguilla japonica*. Dorsal view. NRM 36617. China, Guangzhou [Canton], 1879. Photo: Anders Silfvergrip.

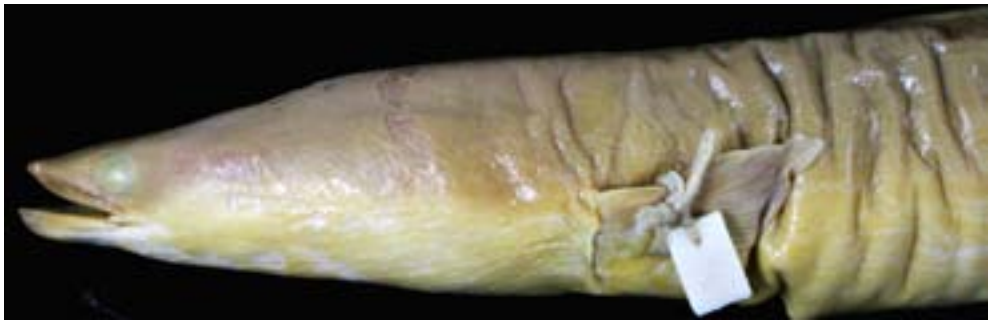


Figure 45. *Anguilla japonica*. Left side lateral view. NRM 36616. China, Hong Kong fish market, 1879. Photo: Anders Silfvergrip.

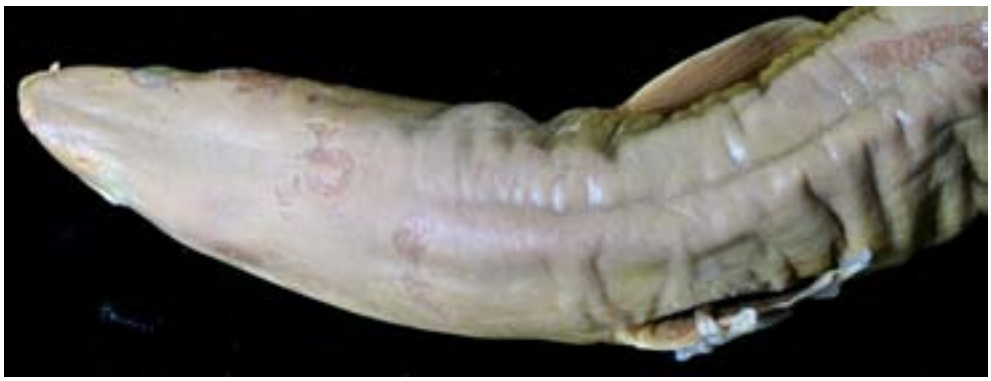


Figure 46. *Anguilla japonica*. Dorsal view. NRM 36616. China, Hong Kong fish market, 1879. Photo: Anders Silfvergrip.

Figure 47. *Anguilla marmorata*. Natal, South Africa. 10 June 1984. IGFA World record (16,36 kg) by Ferdie Van Nooten. Photo: courtesy by IGFA (www.igfa.org).

Figure 48. *Anguilla marmorata* Photo: Jeffrey T. Williams.

Figure 49. *Anguilla marmorata*. NRM 29234. 447 mm TL. Japan, 1914. Photo: Anders Silfvergrip.

Figure 50. *Anguilla marmorata*. NRM 29234. 447 mm TL. Japan, 1914. Photo: Anders Silfvergrip.

Figure 51. *Anguilla megastoma*. 574 mm SL. Opunohu river, Moorea, French Polynesia. Photo: Jeffrey T. Williams.

Figure 52. *Anguilla megastoma*. 574 mm SL. Opunohu river, Moorea, French Polynesia. Photo: Jeffrey T. Williams.

Figure 53. *Anguilla megastoma*. Left side lateral view. ZMUC P313482. Photo: Anders Silfvergrip.

Figure 54. *Anguilla megastoma*. Dorsal view. ZMUC P313482. Photo: Anders Silfvergrip.

Figure 55. *Anguilla mossambica*. Left side lateral view. NRM 8255. 513 mm TL (upper) and 491 mm TL (lower). Photo: Anders Silfvergrip.

Figure 56. *Anguilla mossambica*. Dorsal view. NRM 8255. 513 mm TL (upper) and 491 mm TL (lower). Photo: Anders Silfvergrip.

Figure 57. *Anguilla mossambica*. Right side lateral view (picture reversed). ZMUC P 313455. Photo: Anders Silfvergrip.

Figure 58. *Anguilla mossambica*. Right side lateral view (picture reversed). ZMUC P 313455. Photo: Anders Silfvergrip.

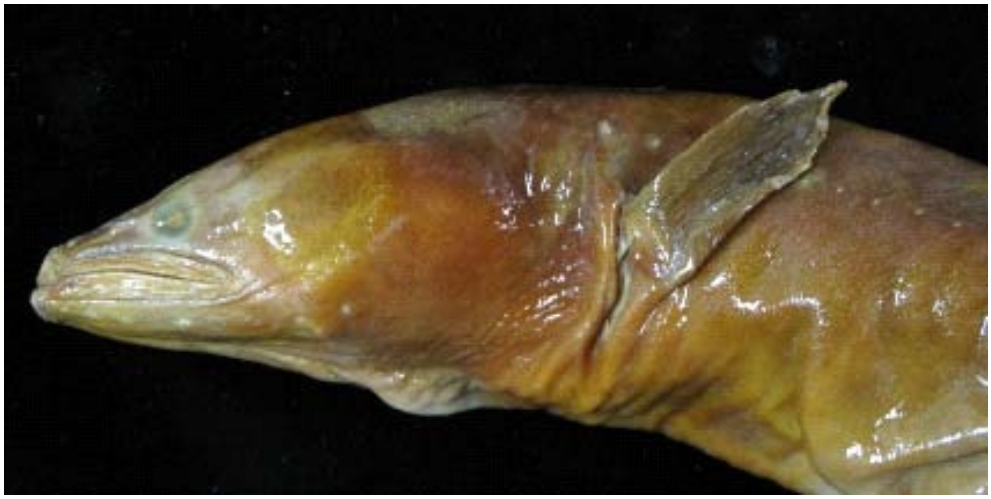


Figure 59. *Anguilla reinhardti*. Left side lateral view. ZMUC P313461. Photo: Anders Silfvergrip.

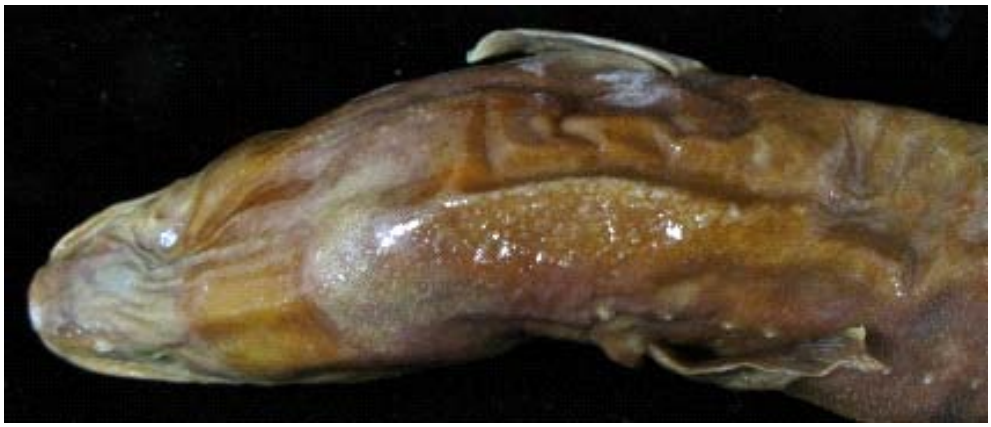


Figure 60. *Anguilla reinhardti*. Left side lateral view. ZMUC P313461. Photo: Anders Silfvergrip.

Figure 61. *Anguilla reinhardti.* 40 km SE Taipei, Ilan City, fish market near train station, 2002. Imported specimen. Photo: Te-Yu Liao.

Figure 62. *Anguilla reinhardti*. 40 km SE Taipei, Ilan City, fish market near train station, 2002. Imported specimen. Photo: Te-Yu Liao.

Figure 63. Mixture of *Anguilla reinhardti* (marbled coloration) and *A. japonica* (plain coloration). 40 km SE Taipei, Ilan City, fish market near train station, 2002. Imported specimens of *A. reinhardti*. Photo: Te-Yu Liao.

Figure 64. *Anguilla rostrata*. NRM 8234. 685 mm TL. Puerto Rico, Arecibo. 1871.
Photo: Anders Silfvergrip.

Figure 65. *Anguilla rostrata*. Glass eel. Photo: Guy Verreault.

Figure 66. *Anguilla rostrata*. Photo: Guy Verreault.

Appendix – Trade Photographs

Figure 67. Moray eels (Muraenidae). Fishmarket near Taipei. Photo: Håkan Wickström

Figure 68. Pike conger eels (Muraenesocidae). Fishmarket near Taipei. Photo: Håkan Wickström

Appendix – Molecular identification

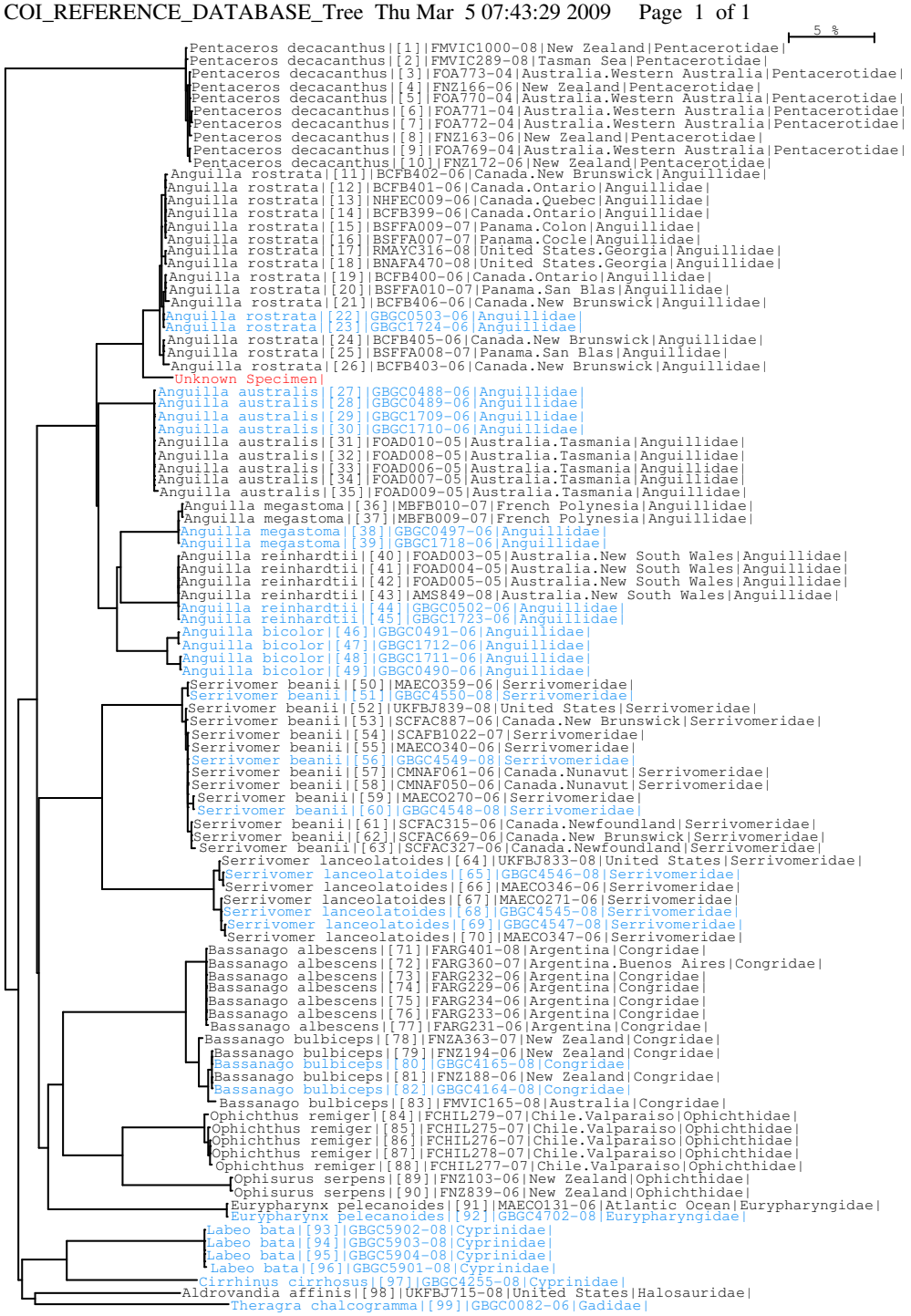


Figure 69. Example of species identification using the COI gene. Sequence (EU266379, identified as *Anguilla japonica*) submitted (November 2007) to GenBank by An *et al.* but yet not available in CBOL. The Kimura tree retrieved from BOLD home page (www.boldsystems.org) with specimen indicated as "Unknown Specimen" in red color. Compare with BLAST tree in Figure 70.

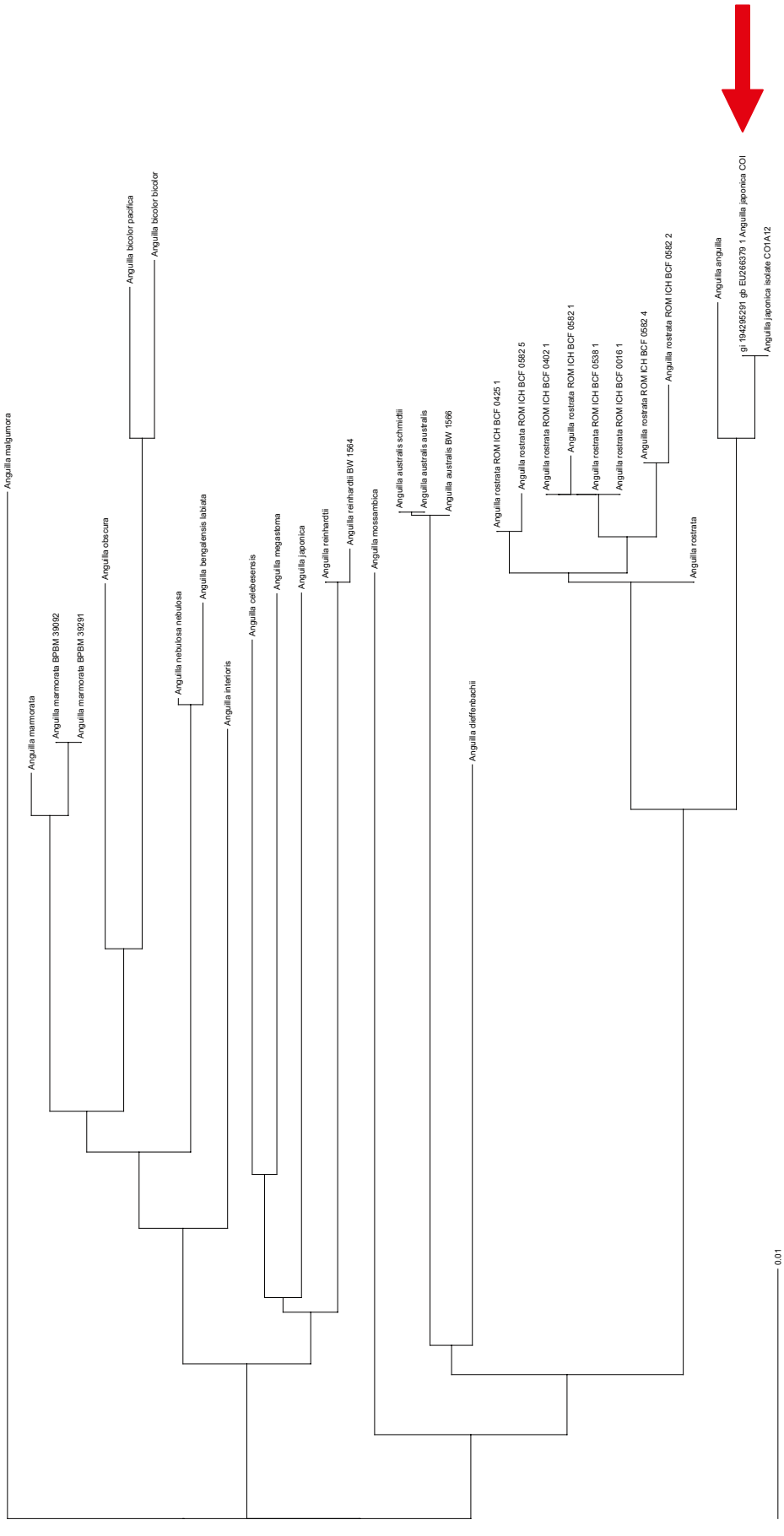


Figure 70. Example of species identification using a COI gene sequence (EU266379, *Anguilla japonica*) recently submitted to GenBank by An *et al.* (submitted November 2007) and not available in CBOL. The fast minimum evolution tree retrieved from BLAST home page (http://blast.ncbi.nlm.nih.gov) and redrawn using TreeViewX 0.5.0 (Page 2005). Compare with Kimura tree in Figure 69.

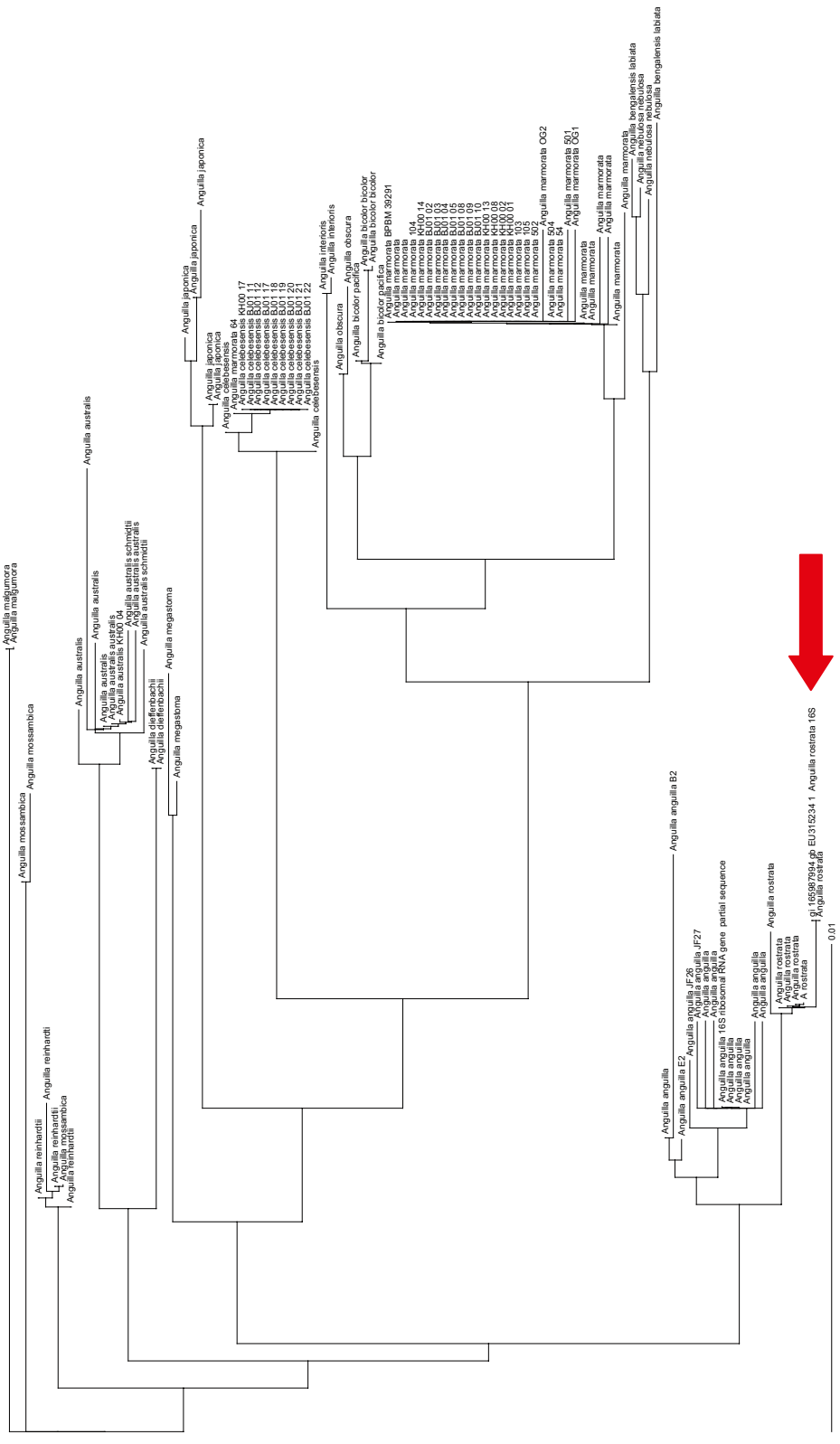


Figure 71. Example of species identification using 16S rRNA of GenBank sample EU315234 (*Anguilla rostrata*). The fast minimum evolution tree retrieved from BLAST home page (http://blast.ncbi.nlm.nih.gov) and redrawn using TreeViewX 0.5.0 (Page 2005).

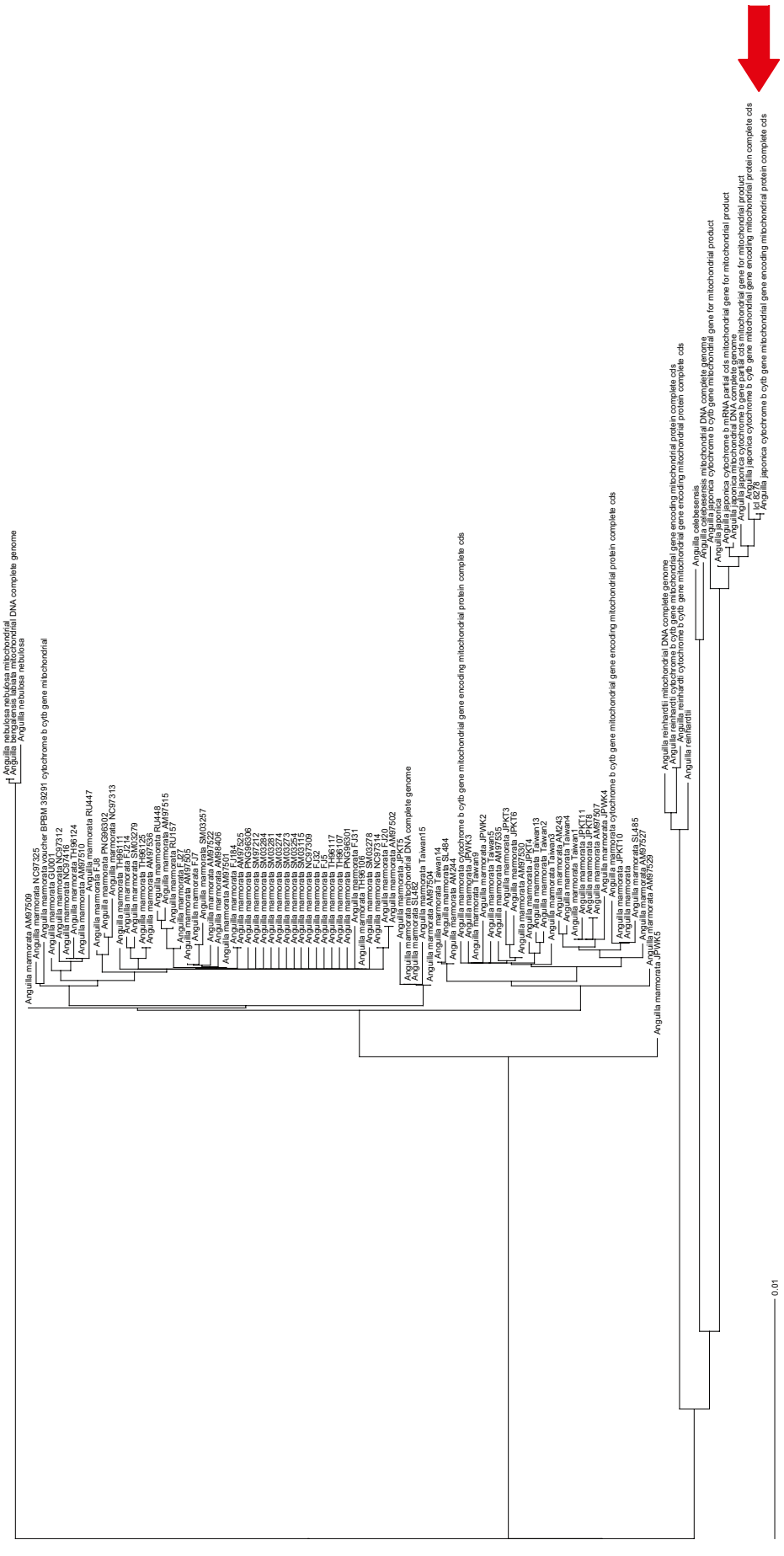


Figure 72. Example of species identification using cytochrome b of GenBank sample AF006703 (*Anguilla japonica*). The fast minimum evolution tree retrieved from BLAST home page (http://blast.ncbi.nlm.nih.gov) and redrawn using TreeViewX 0.5.0 (Page 2005).

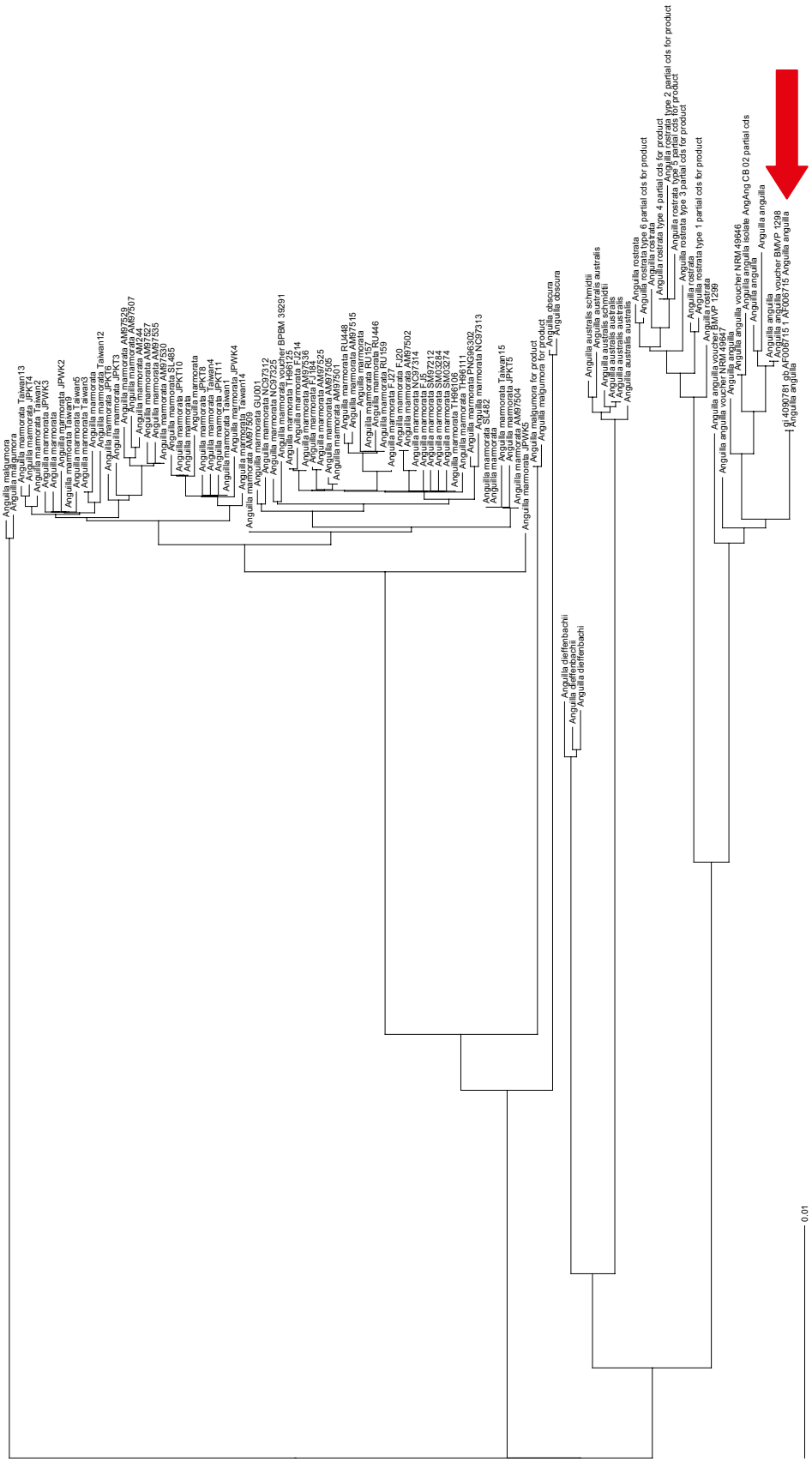


Figure 73. Example of species identification using cytochrome b of GenBank sample AF006715 (*Anguilla anguilla*) using fast minimum evolution tree retrieved from BLAST home page (http://blast.ncbi.nlm.nih.gov).

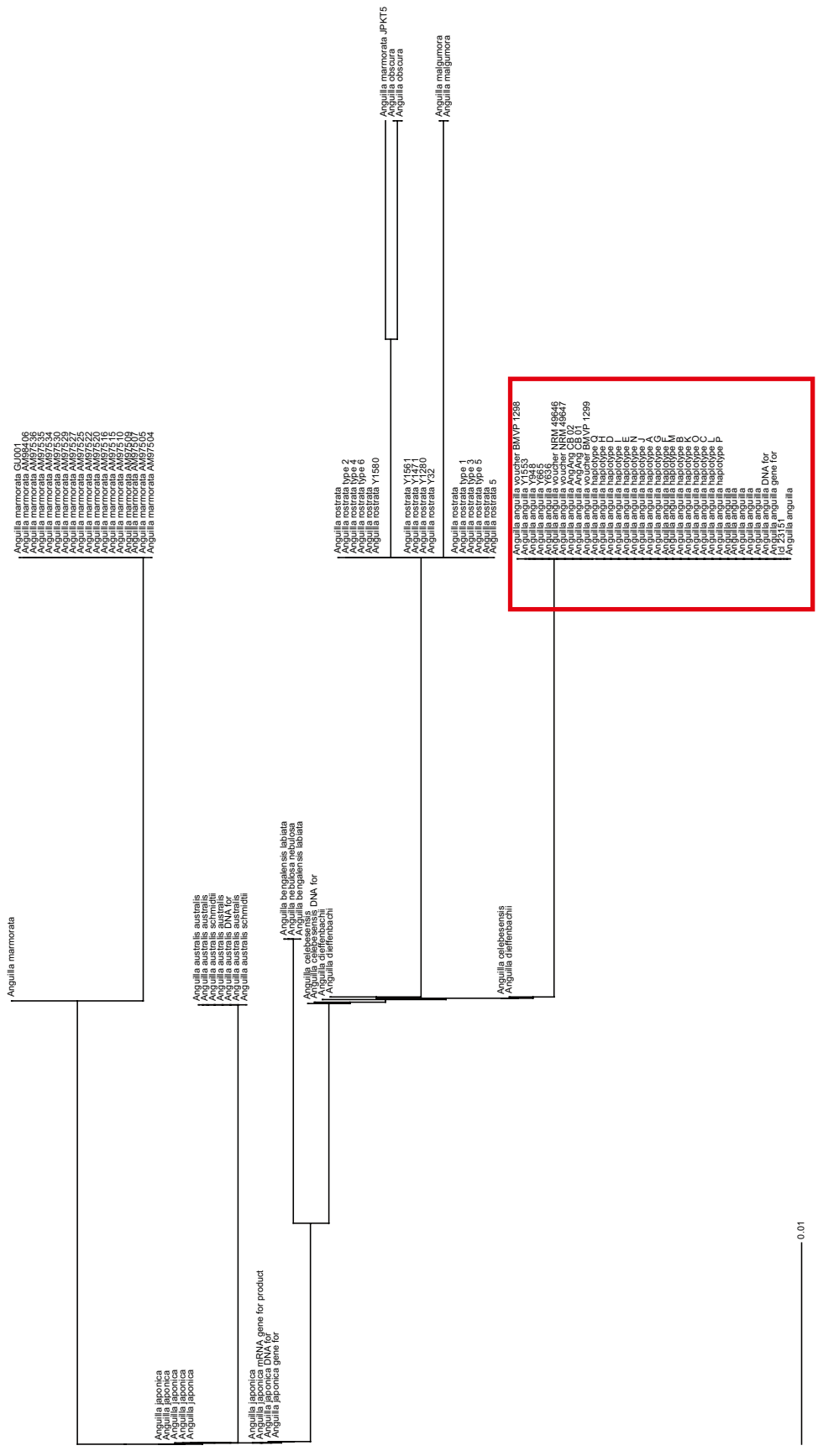


Figure 74. Example of species identification using a 47 basepair *Anguilla anguilla* species specific marker, CTTTACTACGGCTCATACCTTTACATAGAAACATGAAACATTGGAGT, using fast minimum evolution tree retrieved from BLAST home page (http://blast.ncbi.nlm.nih.gov).

CITES Identification Guide to the Freshwater eels (Anguillidae)

with Focus on the European eel *Anguilla anguilla*

REPORT 5943

SWEDISH EPA
ISBN 91-620-5943-9
ISSN 0282-7298

The recruitment of the European eel *Anguilla anguilla* has declined drastically during the last decades. One reason is that the species is widely traded. The European eel is therefore listed in Appendix II of CITES. It is also listed as Critically Endangered in the IUCN Red List. This identification guide aids the enforcement of the CITES listing by providing those in need to identify the European eel with the necessary protocols and background information.

The guide describes suggested protocols for Customs officers, such as sampling procedures and choice of accredited institutions for species identification. Institutions shall have documented capacity for morphological and molecular identification as well as long term storage of tissue samples. The guide also details the protocols for both morphological and molecular identification.

Swedish EPA SE-106 48 Stockholm. Visiting address: Stockholm – Valhallavägen 195, Östersund – Forskarens väg 5 hus Ub, Kiruna – Kaserngatan 14. Tel: +46 8-698 10 00, fax: +46 8-20 29 25, e-mail: registrator@naturvardsverket.se Internet: www.naturvardsverket.se **Orders** Ordertel: +46 8-505 933 40, orderfax: +46 8-505 933 99, e-post: natur@cm.se Adress: CM Gruppen AB, Box 110 93, SE-161 11 Bromma. Internet: www.naturvardsverket.se/bokhandeln