Environmental sustainability assessment of farmed freshwater eels from China, Japan, South Korea, and Taiwan produced in ponds

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Species:	American eel (*Anguilla rostrata*), European eel (*Anguilla anguilla*), Japanese eel (*Anguilla japonica*)
Location:	China, Japan, South Korea, Taiwan
Gear:	Ponds
Type:	Farmed
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Assessed using Seafood Watch Aquaculture Standard v2

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About Seafood Watch

Monterey Bay Aquarium's Seafood Watch program evaluates the ecological sustainability of wild-caught and farmed seafood commonly found in the United States marketplace. Seafood Watch defines sustainable seafood as originating from sources, whether wild-caught or farmed, which can maintain or increase production in the long-term without jeopardizing the structure or function of affected ecosystems. Seafood Watch makes its science-based recommendations available to the public in the form of regional pocket guides that can be downloaded from www.seafoodwatch.org. The program's goals are to raise awareness of important ocean conservation issues and empower seafood consumers and businesses to make choices for healthy oceans.

Each sustainability recommendation on the regional pocket guides is supported by a Seafood Watch Assessment. Each assessment synthesizes and analyzes the most current ecological, fisheries and ecosystem science on a species, then evaluates this information against the program's conservation ethic to arrive at a recommendation of "Best Choices," "Good Alternatives" or "Avoid." This ethic is operationalized in the Seafood Watch standards, available on our website here. In producing the assessments, Seafood Watch seeks out research published in academic, peer-reviewed journals whenever possible. Other sources of information include government technical publications, fishery management plans and supporting documents, and other scientific reviews of ecological sustainability. Seafood Watch Research Analysts also communicate regularly with ecologists, fisheries and aquaculture scientists, and members of industry and conservation organizations when evaluating fisheries and aquaculture practices. Capture fisheries and aquaculture practices are highly dynamic; as the scientific information on each species changes, Seafood Watch's sustainability recommendations and the underlying assessments will be updated to reflect these changes.

Parties interested in capture fisheries, aquaculture practices and the sustainability of ocean ecosystems are welcome to use Seafood Watch assessments in any way they find useful.

Guiding Principles

Seafood Watch™ defines sustainable seafood as originating from sources, whether fished[1] or farmed, that can maintain or increase production in the long-term without jeopardizing the structure or function of affected ecosystems.

The following **guiding principles** illustrate the qualities that aquaculture must possess to be considered sustainable by the Seafood Watch program:

Seafood Watch will:

- Support data transparency and therefore aquaculture producers or industries that make information and data on production practices and their impacts available to relevant stakeholders.
- Promote aquaculture production that minimizes or avoids the discharge of wastes at the farm level in combination with an effective management or regulatory system to control the location, scale and cumulative impacts of the industry's waste discharges beyond the immediate vicinity of the farm.
- Promote aquaculture production at locations, scales and intensities that cumulatively maintain the functionality of ecologically valuable habitats without unreasonably penalizing historic habitat damage.
- Promote aquaculture production that by design, management or regulation avoids the use and discharge of chemicals toxic to aquatic life, and/or effectively controls the frequency, risk of environmental impact and risk to human health of their use.
- Within the typically limited data availability, use understandable quantitative and relative indicators to recognize the global impacts of feed production and the efficiency of conversion of feed ingredients to farmed seafood.
- Promote aquaculture operations that pose no substantial risk of deleterious effects to wild fish or shellfish populations through competition, habitat damage, genetic introgression, hybridization, spawning disruption, changes in trophic structure or other impacts associated with the escape of farmed fish or other unintentionally introduced species.
- Promote aquaculture operations that pose no substantial risk of deleterious effects to wild populations through the amplification and retransmission of pathogens or parasites.
- Promote the use of eggs, larvae, or juvenile fish produced in hatcheries using domesticated broodstocks thereby avoiding the need for wild capture.

1 "Fish" is used throughout this document to refer to finfish, shellfish and other invertebrates.

- Recognize that energy use varies greatly among different production systems and can be a major impact category for some aquaculture operations, and also recognize that improving practices for some criteria may lead to more energy intensive production systems (e.g., promoting more energy intensive closed recirculation systems).

Once a score and rank has been assigned to each criterion, an overall seafood recommendation is developed on additional evaluation guidelines. Criteria ranks and the overall recommendation are color-coded to correspond to the categories on the Seafood Watch pocket guide:

Best Choices/Green: Are well managed and caught or farmed in environmentally friendly ways.

Good Alternatives/Yellow: Buy, but be aware there are concerns with how they're caught or farmed.

Avoid/Red: Take a pass on these. These items are overfished or caught or farmed in ways that harm other marine life or the environment.

Final Seafood Recommendation — China

European Eel, Japanese Eel, American Eel, Unagi

Anguilla anguilla, Anguilla japonica, Anguilla rostrata

Pond (still, greenhouse, flow-through)

FINAL RANK	RED

OVERALL RANKING	
Final Score	0.72
Initial rank	RED
Red Criteria	6
Intermediate Rank	RED
Critical Criteria?	NO

Criterion	Score (0-10)	Rank	Critical?
C1 Data	3.06	RED	n/a
C2 Effluent	2.00	RED	NO
C3 Habitat	4.46	YELLOW	NO
C4 Chemicals	0.00	RED	NO
C5 Feed	5.26	YELLOW	NO
C6 Escapes	3.00	RED	NO
C7 Disease	2.00	RED	NO
C8 Source	0.00	RED	n/a
C9X Wildlife mortalities	-6.00	YELLOW	NO
C10X Introduced species escape	-8.00	RED	n/a
Total	5.78		
Final Score	0.72		

Scoring note – scores range from zero to ten where zero indicates very poor performance and ten indicates the aquaculture operations have no significant impact.

Summary
The final numerical score for eel (*Anguilla anguilla, Anguilla japonica,* and *Anguilla rostrata*) farmed in pond culture systems in China is 0.72. The low numerical score along with six red criteria resulted in an overall red ranking.

Final Seafood Recommendation — Japan

European Eel, Japanese Eel, American Eel, Unagi

Anguilla anguilla, Anguilla japonica, Anguilla rostrata

Pond (still, greenhouse, flow-through)

FINAL RANK	RED

OVERALL RANKING	
Final Score	1.25
Initial rank	RED
Red Criteria	5
Intermediate Rank	RED
Critical Criteria?	NO

Criterion	Score (0-10)	Rank	Critical?
C1 Data	3.06	RED	n/a
C2 Effluent	2.00	RED	NO
C3 Habitat	4.70	YELLOW	NO
C4 Chemicals	4.00	YELLOW	NO
C5 Feed	5.26	YELLOW	NO
C6 Escapes	3.00	RED	NO
C7 Disease	2.00	RED	NO
C8 Source	0.00	RED	n/a
C9X Wildlife mortalities	-6.00	YELLOW	NO
C10X Introduced species escape	-8.00	RED	n/a
Total	10.02		
Final Score	1.25		

Scoring note – scores range from zero to ten where zero indicates very poor performance and ten indicates the aquaculture operations have no significant impact.

Summary

The final numerical score for eel (*Anguilla anguilla, Anguilla japonica,* and *Anguilla rostrata*) farmed in pond culture systems in Japan 1.25, and with 5 red criteria the final ranking is red overall.

Final Seafood Recommendation – Republic of China (Taiwan)

European Eel, Japanese Eel, American Eel, Unagi

Anguilla anguilla, Anguilla japonica, Anguilla rostrata

Pond (still, greenhouse, flow-through)

FINAL RANK	RED

OVERALL RANKING	
Final Score	0.70
Initial rank	RED
Red Criteria	6
Intermediate Rank	RED
Critical Criteria?	NO

Criterion	Score (0-10)	Rank	Critical?
C1 Data	3.06	RED	n/a
C2 Effluent	2.00	RED	NO
C3 Habitat	4.29	YELLOW	NO
C4 Chemicals	0.00	RED	NO
C5 Feed	5.26	YELLOW	NO
C6 Escapes	3.00	RED	NO
C7 Disease	2.00	RED	NO
C8 Source	0.00	RED	n/a
C9X Wildlife mortalities	-6.00	YELLOW	NO
C10X Introduced species escape	-8.00	RED	n/a
Total	5.61		
Final Score	0.70		

Scoring note – scores range from zero to ten where zero indicates very poor performance and ten indicates the aquaculture operations have no significant impact.

Summary

The final numerical score for eel (*Anguilla anguilla, Anguilla japonica,* and *Anguilla rostrata*) farmed in pond culture systems in Taiwan is 0.70. The low numerical score along with six criteria resulted in an overall red ranking.

Final Seafood Recommendation – South Korea

European Eel, Japanese Eel, American Eel, Unagi

Anguilla anguilla, Anguilla japonica, Anguilla rostrata

Pond (still, greenhouse, flow-through)

FINAL RANK	RED

OVERALL RANKING	
Final Score	1.21
Initial rank	RED
Red Criteria	5
Intermediate Rank	RED
Critical Criteria?	NO

Criterion	Score (0-10)	Rank	Critical?
C1 Data	3.06	RED	n/a
C2 Effluent	2.00	RED	NO
C3 Habitat	4.40	YELLOW	NO
C4 Chemicals	4.00	YELLOW	NO
C5 Feed	5.26	YELLOW	NO
C6 Escapes	3.00	RED	NO
C7 Disease	2.00	RED	NO
C8 Source	0.00	RED	n/a
C9X Wildlife mortalities	-6.00	YELLOW	NO
C10X Introduced species escape	-8.00	RED	n/a
Total	9.72		
Final Score	1.21		

Scoring note – scores range from zero to ten where zero indicates very poor performance and ten indicates the aquaculture operations have no significant impact.

Summary

The final numerical score for eel (*Anguilla anguilla, Anguilla japonica,* and *Anguilla rostrata*) farmed in pond culture systems in South Korea is 1.21, and with five red criteria the final ranking is red overall.

European Eel, Japanese Eel, American Eel, Unagi

Anguilla anguilla, Anguilla japonica, Anguilla rostrata

Pond (still, greenhouse, flow-through)

Criterion	China	Japan	Taiwan	South Korea
C1 Data	3.06	3.06	3.06	3.06
C2 Effluent	2.00	2.00	2.00	2.00
C3 Habitat	4.46	4.70	4.29	4.40
C4 Chemicals	0.00	4.00	0.00	4.00
C5 Feed	5.26	5.26	5.26	5.26
C6 Escapes	3.00	3.00	3.00	3.00
C7 Disease	2.00	2.00	2.00	2.00
C8 Source	0.00	0.00	0.00	0.00
C9X Wildlife mortalities	-6.00	-6.00	-6.00	-6.00
C10X Introduced species escape	-8.00	-8.00	-8.00	-8.00
Total	5.78	10.02	5.61	9.72
Final Score	0.72	1.25	0.70	1.21

Summary

This table compiles the scores from the four previous tables so as to facilitate comparison between the four countries included in this assessment. Upon closer review, it becomes evident that the only two criteria that vary between countries are Habitat (C3) and Chemicals (C4). The final scores for all four countries vary by only 0.55 and every country receives a red AVOID ranking overall.

Executive Summary

This assessment was originally published in October 2014 and reviewed for any significant changes in July 2021. No changes were made to the body of the report. Please see *Appendix 2* *for details of review.*

Since the late 1950s, aquaculture has played a growing role in the supply of eel products, and now accounts for over 95% of global eel production by volume. In 2010, over 270,000 metric tons (mt) of farmed eel[2] were produced globally, and China, Japan, Taiwan and Korea accounted for approximately 96% of this production. Pond systems, including outdoor, greenhouse, and flow-through ponds are the predominant production systems employed in these countries and, hence, are the focus of this assessment. The United States ranks as the 6th largest importer of eel products worldwide, but total US imports are less than one tenth (by quantity) of those of the top importers.

A lack of complete, detailed, and independent data available in English presented a significant challenge in conducting this assessment. Some valuable data were collected from government websites, academic literature, grey literature, and personal communications with experts involved in international eel trade and aquaculture. From these multiple sources, sufficient summaries of eel aquaculture practices in Asia were analyzed and informed this assessment. Nonetheless, Seafood Watch is open to reviewing this assessment in the future should more data become available.

Criterion C2 (effluent) scored 2 out of 10, due to the high discharge rate of pond culture systems (10%–35% daily exchange) and the presence of an established regulatory system that lacks transparency and evidence of enforcement in all four countries. Similarly, Criterion C3 (habitat) received an overall score ranging from 4.29 to 4.70 out of 10 because eel aquaculture in ponds is shown to have low habitat conversion rates, however, the regulatory and management regimes in place are lacking in transparency and enforcement, which lead to a low effectiveness score for Factor 3.2b. The final score for Criterion C3 is reported as a range because slight variability in the management regimes across regions necessitated individual country-specific analysis to be conducted for this criterion.

Two assessments were conducted for Criterion C4 (chemical use) due to significant differences in practices applied in various countries. For China and Taiwan, a score of 0 (red ranking) is the result of the use of banned chemical substances (e.g., Malachite green) in farmed eel products. For eel cultured in Japan and South Korea, the chemical criterion receives a score of 4 (yellow) because, although there is evidence that a significant amount of chemicals are used, there have been no reports of the use of banned chemical substances or development of microbial

[2]Data from FAO FishStatJ 2013. Many aspects of the international trade of eels, in particular the lack of identification to the species level, make it challenging to accurately record the industry's production statistics, but this is the most robust number available.

resistance. The high-exchange pond systems employed in eel culture, however, do risk the release of chemicals into the surrounding environment.

Criterion C5 (feed) received a final score of 5.26 (yellow), due to the moderate degree of wild fish used in eel feed (score of 6.53 for Factor 5.1), the 32.9% net protein loss that occurs in eel farming (score of 6 for Factor 5.2), and the relatively high feed footprint (22.96 hectares) resulting principally from the large area of ocean appropriated for feed production (score of 2 for Factor 5.3). These scores are driven by a relatively high aquatic feed inclusion rate (62.5%), however, much of this (84%) is sourced from processing byproducts as opposed to whole fish, resulting in a moderate score for the Feed criterion.

The impact of escapes from eel culture ponds in Asia was determined to be high (score of 3, red) due to a 'moderate-high' escape risk associated with high-exchange pond culture systems. Recent and ongoing reports on non-native eel species in streams and rivers in Japan, China and Taiwan lead to a 'moderate' invasiveness score.

Eel diseases and pathogens are reported with relatively high frequency in each of the four assessed countries, and the nature of the production systems employed (pond and/or flow-through) allow for significant amounts of water to exchange into the natural environment, suggesting that release of pathogens or disease from farm sites is likely. Resultantly, Criterion C7 (pathogens) scored 2 overall and received a red ranking.

Criterion C8 scored 0 overall, and ranked red because the eel aquaculture industry remains fully reliant on wild-caught broodstock due to the ongoing challenges to close the lifecycle of eel species for domestication.

No information on wildlife and predator mortalities was available at the time of this report, however, it is reasonable to presume that wildlife interact with eel ponds and that some mortality is likely to occur. Exceptional Criterion 9X scores -6 out of -10 based on unknown species status and unknown population-level impacts of mortalities.

Exceptional Criterion 10X (introduced species escapes) received a score of -8 due to the high dependency on international or trans-waterbody live animal shipments and high biosecurity concerns of both the source (wild-caught glass eels) and destination (pond culture systems) of the animal shipments.

The variation in scores for the Chemical Use and the Habitat Criterions resulted in a slight discrepancy in the final numerical scores for eel cultured in each of the four countries, with China scoring 1.35, Japan scoring 1.88, Taiwan scoring 1.33, and South Korea scoring 1.84. Despite this nominal variation in numerical scoring, the final ranking for eel culture in pond systems in China, Taiwan, Japan and South Korea was red, and the overall recommendation is 'Avoid.'

Introduction

An interim update of this assessment was conducted in July 2021. This section was updated with new information. The interim update can be found in Appendix 2 at the end of this document.

Scope of the analysis and ensuing recommendation

Species
European eel *(Anguilla anguilla),* Japanese eel *(Anguilla japonica),* American eel *(Anguilla rostrata)*

Geographic coverage
China, Japan, Republic of China (Taiwan) and Republic of Korea

Production Methods
Eels are raised in a variety of production systems, from earthen ponds to highly technical recirculating aquaculture systems (RAS). RAS are used predominantly in Europe, and global production volumes from these systems are minimal compared to pond production in Asia; as such this assessment focuses on eel cultured in pond systems (including outdoor, greenhouse and flow-through ponds), which are the predominant production systems employed in China, Japan, Taiwan and South Korea.

Species Overview

There are 19 species and sub-species classified under the genus *Anguilla*, most of which are catadromous, meaning that they migrate from rivers and other inland water sources to the sea in order to breed. Of these 19 species and sub-species, only three are currently of interest to this assessment due to their dominance in the US market place: *A. anguilla* (European eel), *A. japonica* (Japanese eel), and *A. rostrata* (American eel). It should be noted that as the dynamics of the global trade in *Anguilla* juveniles (known as "glass eels") continues to shift due to change in species availability. Additionally, a greater diversity of eel species are starting to be farmed in Asia, including *A. marmorata, A. bicolor*, *A. mossambica*, and *A. luzonesis,* and while these are likely to become more common in the US marketplace in coming years (Crook & Nakamura, 2013), current production levels are small and these species are not covered in the scope of this assessment.

Eels have an extremely complex lifecycle and exhibit broad geographic distributions, which have made them difficult to research and vulnerable to overexploitation. The Japanese eel is distributed across East Asia, inhabiting rivers and streams of China, Japan, Taiwan, Korea, and the northern Philippines during the freshwater component of its lifecycle and subsequently migrating some 3000 km to their spawning grounds west of the Mariana Islands in the mid-Pacific (Ottolenghi et al. 2004). The European eel and American eel are both believed to spawn in the Sargasso Sea (mid-Atlantic Ocean), but disperse to European and American coasts and rivers, respectively.

The newly-hatched larval form of eels is known as a leptocephalus and is a marine planktonic stage. As they enter the continental shelf from their deep-sea spawning grounds, leptocephali metamorphose into glass eels (juveniles), a transparent stage that more closely resembles the adult form. Glass eels become progressively more pigmented, a life stage known as "elvers." Once the eels enter freshwater, several adult stages (known as "yellow" and "silver" eels) lead ultimately to sexual maturation.

The migration pattern of each species differs in their seasonality and duration. For example, the Japanese eel will typically disperse in coastal areas and rivers as elvers within one year of hatching, while European eels will spend approximately three years at sea as leptocephali before migrating to coastal areas and freshwater (Ottolenghi et al. 2004). The European eel will spawn in winter and spring, while the American eel spawns in the fall (Ottolenghi et al. 2004).

The Japanese eel and the European eel have been the most commercially important *Anguilla* species to date, with modest contributions to global production from the American eel and the short finned eel (*A. australis*) (Ottolenghi et al. 2004, Crook 2010). Increased fishing pressure along with deteriorating environmental conditions have caused significant declines in global eel populations over the past 30 years (Casselman and Cairns 2009).

The European eel is currently listed as critically endangered on the IUCN Red List and in 2007 it was listed in Appendix II of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES). The Japanese eel has been under assessment by the IUCN for the past year and was listed as endangered in June 2014[3]. This species has also been designated as endangered by the Japanese Environment Ministry[4/5] and is considered to be of critical concern by the East Asia Eel Resource Consortium[6]. Similarly, the American eel has been listed as threatened by Canada's Committee on the Status of Endangered Wildlife in Canada (COSEWIC)[7] and is currently under review by the US Fish and Wildlife Services[8] for inclusion on their endangered species list.

Production statistics

Eels are harvested for global trade and consumption at all stages of their lifecycle. Since the late 1950s, aquaculture has played a growing role in the supply of eel products and now accounts for over 95% of global eel production for food trade by volume (Food and Agriculture Organization (FAO) 2013). Despite the fact that capture fisheries represent a small portion of

[3] http://www.iucnredlist.org/details/166184/0
[4] http://japandailypress.com/japanese-eel-added-to-environment-ministrys-vulnerable-list-1412167/
[5] http://www.japantimes.co.jp/life/2013/02/02/environment/ministry-officially-classifies-japanese-eel-as-species-at-risk-of-extinction/#.UpKiTdKsiM4
[6] http://easec.info/EASEC_WEB/index_files/EASECdeclarations(Final).pdf
[7] http://www.cosewic.gc.ca/eng/sct1/searchdetail_e.cfm?id=891
[8] http://www.fws.gov/northeast/newsroom/eels.html

overall eel production by volume, they still play an important role in the industry, as eel aquaculture remains entirely dependent on wild-caught broodstock. As such, capture fisheries now target predominantly glass eels and elvers to supply aquaculture operations. Crook and Nakamura (2013) note that prior to 1990 eel farming was mostly carried out using species of local provenance, however, a sharp decline of Japanese eel populations in the late 1990s prompted the development of an international trade in glass eels. Today, instability in the supply of glass eels has made them an extremely valuable product; so much so that one anecdotal account in a seafood industry magazine reported a market price of US$35,000/kg (approximately US$7 per individual) for glass eels in 2012[9], however, this value was subsequently questioned by other industry experts.

In 2010, over 270,000 metric tons (mt) of farmed eel were produced globally. According to FAO (2013), China accounted for over 78% of that production and a single species (*A. japonica*) is said to have accounted for 95% of globally farmed eel. Although there is likely some truth to these figures, many aspects of the international trade of eels make it particularly challenging to accurately record the industry's production statistics. For example, it is known that eel farmers in Asia will stock different species depending on market availability and price, however, all production either gets recorded as Japanese eel (*A. japonica*) or simply is not recorded to a species-specific level (Crook pers. comm., Ringuet et al. 2002). These examples of gaps and deficiencies in the data are simply a reality within the eel trade; as such, the author would like to preface this report by acknowledging that production statistics included herein are unlikely to be completely reflective of current practices, but they are as accurate as possible given the available data.

Asia has been a dominant player in eel aquaculture with China, Japan, Taiwan and Korea accounting for over 96% of global farmed eel production in 2010 (FAO, 2013). Europe is the second largest production region where the Netherlands, Denmark and, to a lesser extent, Spain are the top producing countries in that region.

Import and export sources and statistics

Eels have yet to become a popular food fish in the United States and, as a result, the market for them remains relatively small. The largest single market for eels continues to be for Japanese 'kabayaki' (marinated, grilled eel). The United States ranks as the 6th largest importer of eel products worldwide, but note that US imports are less than one tenth (by quantity) of those of the top importers (FAO 2013). Overall, an estimated 1 575 mt of mixed eel products were imported into the US in 2013, which was valued at $29 million (USDA 2014). A vast majority of eel imports are sourced from China (86%), while Taiwan, Japan, South Korea, Vietnam and Canada supply product to a lesser extent (Agricultural Resource Marketing Center 2013). Note that Vietnam acts as a point of re-exportation, as they do not typically farm eel themselves and, hence, Vietnam is not included in this assessment. Similarly, eel products being imported from Canada are sourced from capture fisheries and are being imported mostly as live elvers (USDA 2013).

[9] http://www.gaalliance.org/mag/2012/Nov-Dec/download.pdf

In 2013, the US exported approximately 1,559 mt of eel products valued at $47 million (USD) (USDA 2013). Live elvers or frozen fillets made up the majority of exported eel products by weight, however, the export of live elvers accounted for 90% of exports by value. Exports of live elvers go primarily to Hong Kong, South Korea, and Belgium, while exports of frozen fillets are destined for South Korea, the Netherland and Brazil (USDA 2013).

Common and market names
Freshwater eel, river eel, common eel, kabayaki, unagi.

Product forms
Farmed eel is typically sold as fillets, either fresh or frozen. Fillets are most commonly marinated and grilled in Japanese cuisine (unagi and kabayaki).

Note that *unagi* refers to freshwater eels of the genus *Anguilla*, while *anago* is prepared from conger eels (family Congridae), which are exclusively marine (Halpin 2007). This report covers only freshwater eels and does not cover conger eels.

Analysis

Scoring guide

- With the exclusion of the Exceptional Criteria (C9X and C10X), all scores result in a zero to ten final score for the criterion and the overall final rank. A zero score indicates poor performance, while a score of ten indicates high performance. In contrast, the two exceptional criteria result in negative scores from zero to minus ten, and in these cases zero indicates no negative impact.
- The full Seafood Watch Aquaculture Criteria that the following scores relate to are available here http://www.seafoodwatch.org/cr/cr_seafoodwatch/content/media/mba_seafoodwatch_aquaculturecriteramethodology.pdf
- The full data values and scoring calculations are available in Appendix 1.

Criterion 1: Data quality and availability

Impact, unit of sustainability and principle

- *Impact: poor data quality and availability limits the ability to assess and understand the impacts of aquaculture production. It also does not enable informed choices for seafood purchasers, nor enable businesses to be held accountable for their impacts.*
- *Sustainability unit: the ability to make a robust sustainability assessment.*
- *Principle: robust and up-to-date information on production practices and their impacts is available to relevant stakeholders.*

Criterion 1 Summary

Data Category	Relevance (Y/N)	Data Quality	Score (0-10)
Industry or production statistics	Yes	5	5
Effluent	Yes	2.5	2.5
Locations/habitats	Yes	2.5	2.5
Chemical use	Yes	2.5	2.5
Feed	Yes	5	5
Escapes, animal movements	Yes	2.5	2.5
Disease	Yes	2.5	2.5
Source of stock	Yes	5	5
Predators and wildlife	Yes	0	0
Other – (e.g., GHG emissions)	no	Not relevant	n/a
Total			**27.5**

C1 Data Final Score	**3.06**	**RED**

Brief Summary

Scientific, publically available data pertaining to the eel aquaculture industry are limited. The few peer-reviewed articles analyzed, in conjunction with government reports, FAO documents, and direct communications with producers have informed this assessment. However, overall data availability is poor and Criterion 1 – Data receives a score of 3.06 out of 10.

Justification of Ranking

Despite the growing importance of aquaculture to both Asia and the global market, robust and reliable data about production levels and farming practices in Asia remain disparate at best. This is particularly true for eel aquaculture because, although it is highly lucrative, it represents a small portion of the overall aquaculture industry in the region. The reliability of government reporting has been brought into question since the Chinese production statistics had to be revised and corrected in the FAO State of the World Fisheries and Aquaculture 2010. The complexity of eel trade and lack of an appropriate traceability system has further challenged the ability to accurately record the species of eels being farmed, production volumes, and typical trade routes (Crook 2010, Crook & Nakamura 2013).

The majority of the data included in this assessment were sourced from government documents, academic literature, and grey literature (typically reports from the Food and Agriculture Organization). None of the data categories assessed, with the exception of production statistics, had well-defined data sets or a significant volume of independent, peer-reviewed literature. Rather, the information and resulting scores are more a patchwork of data from multiple sources that were brought together to inform the assessment. The Effluent (C2) and Habitat (C3) criteria, for example, were informed primarily by environmental laws and regulations available on government websites, while the academic literature provided one-off observations or case studies applicable to these criteria. In the case of predator interactions (C9X) the complete absence of data required that the assessment be informed by insights gleaned from pond culture systems more generally, as well as an applicable precautionary approach.

The Chemical Use (C4), Escapes (C6), and Disease (C7) criteria were informed first and foremost by academic literature that provided snap-shots into what might be typical practice around these points. For Chemical Use (C4), further insights were gathered from the Food and Drug Administration (FDA) shipment inspections and other similar international import control measures. Data for the Feed Criterion (C5) were sourced from an FAO report, academic literature and personal communications with two of the largest eel feed producers in Europe. Although these data provide the best general assessment for the feed criterion, the geographic and temporal differences in feed formulations and the lack of transparency and reporting of specific feed formulations from feed companies present a serious challenge when assessing the feed criterion. A precautionary approach was adopted in light of data gaps, and it was expected that increased data availability would result in an improvement in the feed score. The Source of Stock (C8) criterion received a moderate data quality score because researchers and farmers have yet to be able to fully domesticate eel broodstock, which indicates that all eel aquaculture is dependent on wild fisheries. There remains, however, much ambiguity around the source of wild glass eels for aquaculture in Asia as a result of decreased capture landings and increased cost for certain *Anguilla* species, which has forced farmers to source glass eels from new populations (Crook 2010, Crook and Nakamuta 2013).

Overall, the lack of complete, detailed and independent monitoring (or data collection) for aquaculture in China, Japan, Taiwan and South Korea challenges the ability to carry out an environmental assessment that is adequately informed and appropriately representative of on-the-ground practices. The growing importance of Asian aquaculture to the global market, however, implores the need to consolidate all currently available information so as to highlight areas that require greater transparency.

It should be noted that one of the main challenges in conducting this assessment was the language barrier such that the author of this report has little knowledge of the primary languages spoken in China, Japan, Taiwan or South Korea. Hence, it is possible that more robust data does exist but that it is not available in English at this time. The author did make numerous attempts to contact government employees, researchers, academics and non-governmental organizations in each of the countries included in this assessment via email and phone, however, the vast majority of information requests went unanswered. As a result of the lack of data available at this time, the final data quality score is 3.06 out of 10. Should more data become available in the future these scores will be updated.

Criterion 2: Effluents

Impact, unit of sustainability and principle

- *Impact: aquaculture species, production systems and management methods vary in the amount of waste produced and discharged per unit of production. The combined discharge of farms, groups of farms or industries contributes to local and regional nutrient loads.*
- *Sustainability unit: the carrying or assimilative capacity of the local and regional receiving waters beyond the farm or its allowable zone of effect.*
- *Principle: aquaculture operations minimize or avoid the production and discharge of wastes at the farm level in combination with an effective management or regulatory system to control the location, scale and cumulative impacts of the industry's waste discharges beyond the immediate vicinity of the farm.*

Criterion 2 Summary

Effluent parameters	Value	Score	
F2.1a Biological waste (nitrogen) production per of fish (kg N ton-1)	84.32		
F2.1b Waste discharged from farm (%)	75		
F2 .1 Waste discharge score (0-10)		3	
F2.2a Content of regulations (0-5)	4		
F2.2b Enforcement of regulations (0-5)	0.75		
F2.2 Regulatory or management effectiveness score (0-10)		1.2 – 1.95	
C2 Effluent Final Score		**2.00**	**RED**
Critical?	NO		

Brief Summary

It was calculated that 84.32 kg of nitrogen waste are produced per ton of eel. As 75% of waste is discharged in effluent from flow-through and high-exchange ponds, the waste discharge score is 3 out of 10. While some regulation and management of effluent-related impacts are apparent, evidence of compliance and enforcement is lacking and warrants a precautionary approach. The numerical score for Criterion 2 – Effluent is 2 out of 10.

Justification of Ranking

Factor 2.1 Waste discharge score

The typical feed formulations for eel farming in Asia maintain a protein content of 48% and farming practices result in an economic feed conversion ratio (eFCR) of 1.4[10]. Based on these values, it was calculated that 84.32 kg of nitrogen is produced per ton of eel farmed. The degree to which this waste is discharged varies significantly based on the production system used. For flow-through pond systems it is considered that 100% of the waste produced is discharged into the surrounding environment, whereas pond culture systems that exhibit a daily exchange are considered to discharge only 51% of the waste produced; the remaining 49%

[10] See Criterion 5 for further details

of waste produced remains within the immediate footprint of the farm and is considered in Criterion 3 – Habitat. As both flow-through ponds and ponds with daily exchange (with minimal water retention) are used to a similar degree for eel culture in China, Japan, Taiwan, and South Korea, an average waste discharge rate of 75% was applied to this assessment. As such, 63.24 kg of nitrogen is calculated to be discharged from eel aquaculture ponds as effluent, corresponding to a score of 3 out of 10 for Factor 2.1.

Factor 2.2 Regulatory or management effectiveness score

The regulation and management effectiveness for effluent controls are outlined below—due to variability in national legislative regimes, each country is presented individually. Despite these variations, all four countries received very similar scores for Factor 2.2, wherein they ranged from 1.2 to 1.95.

<u>China</u>

In China, management of effluent from aquaculture is addressed by a number of laws and regulations including the *Fisheries Law*, *Regulation for the Implementation of the Fisheries Law*, *Law on Prevention and Control of Water Pollution*, and the *Marine Environment Protection Law*. In accordance to the aforementioned laws and regulations, the *Water Quality Standards for Fisheries* (1989) was developed and set out specific quantitative standards for 32 different water pollution indicators. These laws and regulations are national standards that are applied by the Bureau of Fisheries, which is a department under the Ministry of Agriculture, but they are typically supplemented by more specific rules and regulations set out by the fisheries departments of specific provinces, autonomous prefectures, counties and cities (FAO 2013b). Fisheries administrations, at or above the county level, are responsible for permitting, monitoring and enforcing regulations of aquaculture operations, which are to be carried out as per the state defined rules and regulations. Unfortunately, the author was not able to retrieve these more regional rules and regulations, but it is likely that these regional rules provide more site-specific regulations for the 32 different water pollution indicators set out by the national regulations, and may provide some control measures to address cumulative impact of effluent. However, in absence of the exact language of regional legislation and regulation, the management effectiveness factors were scored conservatively (2.25 out of 5) as per the available national legislation. According to a 2001 FAO document, there were 2,100 fisheries law enforcement agencies with 30,000 enforcement staff throughout China at the end of 1999. More recent published literature (e.g., Cao et al. 2007; Zhang 2007; Miao & Jiang 2007) denounces the environmental implications of aquaculture waste production in China, which brings into question the ability of enforcement to demonstrably result in compliance. This resulted in a lower overall score (1.25 out of 5) for the enforcement level of effluent regulations. Overall, the management regime for effluent control from aquaculture in China scored 1.75 out of 10 due to the lack of evidence of effective monitoring and enforcement.

<u>Japan</u>

In Japan, effluent discharges are regulated under the *Water Pollution Control Law* (WPCL) (1970) for which the Ministry of the Environment (MoE) is the responsible authority. As per chapter 2 of the WPCL, the MoE has set out national effluent standards in an effort to prevent the pollution of public waters. Furthermore, under the Basic Environmental Law (1993) the MoE established environmental quality standards (EQS) for water pollution of which there are two kinds: those that aim to protect human health and those that aim to protect the living environment. The EQS provide quantitatively set limits for 26 substances and five ecological indicators, which are to be achieved by the governors of each prefecture by the establishment of a “Plan for Reduction of Total Pollution Load”[11]. The listed laws and regulations above suggest that there are control measures for effluent regulations that are applicable to aquaculture operations in Japan, however, it is unclear whether these control measures lead to site-specific discharge limits. The requirement for each prefecture to develop a “plan for reduction of total pollution load” suggests that the control measures likely consider cumulative effects, however, the specific language of the prefecture-level plans could not be found and hence this factor was scored moderately.

Chapter III of the WPCL also makes prefecture governments responsible for continuous monitoring of the conditions of water pollution, of which the results are to be reported back to the MoE. Any industry found to be discharging effluent that exceeds acceptable EQS could be held liable to compensate for damages as per Chapter IV of the WPCL, however, it is not clear how strict enforcement is within the country. In addition to these broad regulations, the Law to Ensure Sustainable Aquaculture Production was passed in 1999 which requires the Fisheries Cooperative Associations—the local governing bodies for fisheries and aquaculture—to develop and implement “aquaculture ground improvement programmes” (FAO 2013*c*). Unfortunately, at the time of this writing, these programs and plans were not publicly available in English, but Yokoyama (2003) identified that the program, although based in legislation, is voluntary and that enforcement has not resulted in full compliance to date.

Overall, the regulatory and management effectiveness for effluent control in Japan scored 1.5 out of 10.

Taiwan

The Environmental Protection Administration (EPA) serves as the lead organization responsible for regulating aquaculture effluent in Taiwan. The national organization houses a department of water quality protection, a department of environmental sanitation, and toxic substance management, as well as a bureau of environmental inspection. Each city and county government also established an environmental protection bureau to enhance the work of the EPA (EPA 2010). The guiding piece of legislation specific to effluent management is the *Water Pollution Control Act (1974,* as amended), under which there is a suite of regulations such as the *Effluent Standard Regulations* (1987, as amended), the *Surface Water Classification and Water Quality Standards* (1985, as amended), and the *Water Pollution Control Measures and Test Reporting Management Regulations* (2006, as amended) that outline specific regulations and discharge limits for various industries, including aquaculture. Under Article 80 of the *Water*

[11] see http://www.env.go.jp/en/water/wq/wp.pdf

Pollution Control Measures and Test Reporting Management Regulations (2006, as amended), general fish farming enterprises are required to keep monthly reports that record the date that wastewater is discharged, method of disposal, quantity of wastewater discharged and the dissolved oxygen level of wastewater at time of disposal. In addition, all aquaculture operations must report the pH, water temperature, biological oxygen demand, chemical oxygen demand, and suspended solids concentration for effluent every six months (Article 83). The *Surface Water Classification and Water Quality Standards* set out additional standards for surface water used for aquaculture. These latter standards include limits for ammonia and total phosphorous concentrations.

Despite the seeming thoroughness of these numerous regulations and legislations, it has been repeatedly highlighted that the lack of an appropriate regulatory regime has had serious implications for the industry (Liao 1998, Liao 2005, Liao & Chao 2007). Liao & Chao (2007) state, "the proliferation of aquaculture ponds was not regulated until several serious problems were encountered that resulted in the collapse of the industry as a whole" (p.167). Given that most of the effluent related legislations and regulations have been in place since the mid-1980s, it is perhaps the lack of enforcement that has undermined the ability of the legislations outlined above to effectively manage the impact of effluent from the aquaculture industry. The EPA and environmental protection bureaus work together to conduct annual water pollution inspections, which are subsequently reported on the Taiwan Environment Data Warehouse[12]. In 2012, 3,159 water pollution inspections were completed across the country and over $8 million (USD) was collected in fines. Unfortunately, inspection reports are aggregated by geographic region and, hence, it is not known how many (if any) inspections took place on aquaculture sites. Overall, the regulatory and management effectiveness for effluent control in Taiwan scored 1.95 out of 10.

South Korea

The regulation and management of aquaculture effluent in Korea is guided primarily by the *Water Quality and Ecosystem Conservation Act (1997)* and the *Enforcement Decree of the Water Quality and Ecosystem Conservation* Act (1997). Together, these two pieces of legislation aim to preserve the quality of public waters (including rivers, lakes, marshes, harbors, ports and coastal waters) from pollution that would be damaging to human health and the environment. The *Water Quality and Ecosystem Conservation Act (1997)* sets out discharge standards for 31 pollution indicators, including organic matter, suspended solids, phosphorous, nitrogen, and chemical pollutants (Republic of Korea Ministry of Environment, n.d.). These standards are applicable to all wastewater discharge facilities, which are defined as "facilities, machines, equipment and other objects that release water quality pollutants" (Article 2-11, *Water Quality and Ecosystem Conservation Act*). The standards are applied "in accordance with the amount of discharged wastewater from facilities by region" (Republic of Korea Ministry of Environment, n.d.), which suggest that they account for cumulative impacts on a regional scale and are likely to lead to site-specific discharge limits. As per the *Enforcement Decree of the Water Quality and*

[12] http://edw.epa.gov.tw/eng/reportStatisticEN.aspx?StatDataID=37

Ecosystem Conservation Act (1997), the Minister of the Environment is responsible for publishing the target water quality and the total amount of water quality pollutants that are to be regulated for specific regions and river systems. Local authorities (the Mayor/governor) can, however, publish more specific water quality regulations for their jurisdiction by submitting a detailed application to the minister of environment. As these acts do not speak specifically to aquaculture, it is unclear how regularly aquaculture effluent is being monitored and if control measures cover all aspects of the production cycle. However in 2003 a Pollutant Discharge Levy Program was initiated that charges business establishments for each pollution unit discharged for 19 different pollutants, including nitrogen and phosphorous. If discharge facilities exceed their allotted loading quantity, they may be required, under Article 9 of the *Enforcement Decree of the Water Quality and Ecosystem Conservation* Act (1997), to install monitoring gauges that automatically transmit measured discharge quantities to the Tele-Monitoring System Control Center.

Enforcement of water quality regulations is carried out by the Water Environment Management Bureau, for which the organizational structure and contact information is available online[13]. There are no data currently available, however, that speak specifically to monitoring or enforcement of aquaculture sites. Due to the lack of transparency in enforcement and uncertainty as to the effectiveness of the established management regime, South Korea received a score of 1.2 (out of 10) for this factor overall.

Summary

Overall, the high discharge rate of pond culture systems combined with a lack of evidence of effective regulatory and management regimes in all four countries resulted in a final score of 2 (out of 10) for the effluent criterion.

[13] http://eng.me.go.kr/content.do?method=moveContent&menuCode=abo_org_contact

Criterion 3: Habitat

Impact, unit of sustainability and principle

- *Impact: Aquaculture farms can be located in a wide variety of aquatic and terrestrial habitat types and have greatly varying levels of impact to both pristine and previously modified habitats and to the critical "ecosystem services" they provide.*
- *Sustainability unit: The ability to maintain the critical ecosystem services relevant to the habitat type.*
- *Principle: aquaculture operations are located at sites, scales and intensities that cumulatively maintain the functionality of ecologically valuable habitats.*

Criterion 3 Summary

Habitat parameters	Value	Score	
F3.1 Habitat conversion and function		6.00	
F3.2a Content of habitat regulations	1.75		
F3.2b Enforcement of habitat regulations	1.25		
F3.2 Regulatory or management effectiveness score		0.875 – 2.1	
C3 Habitat Final Score		**4.29 – 4.70**	**YELLOW**
Critical?	NO		

Brief Summary

The eel aquaculture industry initially developed with little regulatory oversight or planning, however, most ponds are built on former agricultural lands as opposed to virgin ecosystems. While there are shown to be moderate habitat impacts, due to the high density and input-requirements of eel ponds there is little evidence of permanent loss of ecosystem services. Content and enforcement of legislation in place to mitigate habitat impacts is moderate and the final score for Criterion 3 – Habitat is a range of 4.29 to 4.70 out of 10.

Justification of Ranking

Factor 3.1. Habitat conversion and function

Criterion 3 aims to assess the direct habitat impacts that occur as a result of siting aquaculture farms. These impacts may arise from the direct conversion of pristine habitat for aquaculture purposes or the rezoning of previously used habitat. Habitat conversion for the purpose of aquaculture is of concern because it results in a loss of ecosystem services, which may in turn limit the functionality of that ecosystem. Note that this criterion is only concerned with the impacts observed at the farm site and within the allowable zone of effect (AZE). Far-afield impacts resulting from the release of effluent are assessed in criterion C2.

The rapid growth of the eel farming industry in Asia that has occurred over the past two decades transpired with little to no regulatory oversight, particularly in the early years (Liao & Chao 2007). Many small-scale producers started their business by transforming agricultural land into pond culture systems and there is little evidence that this has resulted in permanent loss of ecosystem services. Hall et al. (2011) found that inland eel pond culture can cause far-field eutrophication of surrounding water bodies, however, this is believed to be reversible with fallowing. Typically, this would be considered a moderate impact on habitat functionality and result in a score of 7 (out of 10), but some concerns have been raised regarding the intensive use of freshwater in eel pond culture, which is amplified by the inadequate degree of planning and lack of regulatory oversight during the initial phases of industry development. In some regions, like Taiwan, the persistent drawing of groundwater has resulted in massive land subsidence, sometimes upwards of three meters (Chang 2010, Taiwan Review 2009, Wu 1999). Damage from land subsidence may be rectified by infilling, but it is believed to have a long-lasting negative impact on communities, particularly with the looming threats of sea-level rise and increased flooding associated to climate change. In circumstances where land subsidence does occur, it would be considered a major impact to overall habitat functionality, however, this does not occur in all instances of eel aquaculture development in Asia. As such, this factor results in a median score of 6 (out of 10) in order to maintain an average assessment that is reflective of the eel aquaculture in Asia industry as a whole.

Factor 3.2. Habitat and farm siting management effectiveness (appropriate to the scale of the industry)

<u>China</u>
In China, land and water resources are state owned and, as such, states are responsible for having overall land utilization plans and implementing a system of water withdrawal permits. Under the Regulations for Implementation of the *Fisheries Law* (1987), natural spawning, breeding and feeding grounds of fish, shrimp, crab, shellfish and algae, migration passages, and other environmentally sensitive habitats are protected from aquaculture siting. Additionally, in 2003, the *Environmental Impact Assessment Law* came into effect and expanded the requirement for environmental impact assessments (EIA) to encompass government planning for developments including, but not limited to, aquaculture, animal husbandry and agriculture (FAO, 2013*b)*. Despite the growing legislative environmental protection that speaks to aquaculture siting in China, there have also been continuous efforts to promote the growth and development of the industry. Some have argued that the growth of the industry has occurred at a rate that exceeds the ability of government policies, legislation and enforcement to ensure its sustainable development (Cao et al. 2007, Zhang 2007, Miao & Jiang 2007). Luo, Zhu, & Bao (2009), for example, reported that pre-construction EIAs were still lacking for new farms. The regulatory and management effectiveness received a moderate score of 2.75 out of 5 for having clear regulations requiring EIAs and protection of high-valued habitat, but limited consideration of cumulative impacts, and the industry's future expansion limits remain unaddressed. The siting regulatory or management enforcement factor received a lower score (1.38 out of 5) because, although there are designated responsible government authorities, there is no transparency in the enforcement process nor is there evidence that the limits or defined control measures are being achieved. The overall score was 1.38 out of 10 for China's habitat and farm siting management effectiveness.

Japan

The *Law of Fisheries* (1949, as revised in 1962) provides a national legislative framework for fisheries production systems—where "fisheries" refers to gathering, catching and culturing of aquatic animals and plants. There exists an environmental impact assessment Law, which came into force in 1997, however, this law does not speak to aquaculture directly. In 1999, the *Law to Ensure Sustainable Aquaculture Production* was passed with the intent to prevent self-induced environmental deterioration around fish farms. Subsequent to the passing of this law, the Ministry of Agriculture, Forestry and Fisheries developed basic voluntary guidelines for water quality, for sediment condition on the bottom of aquaculture grounds, and for the health condition of culture fish (Takeda, 2010). To the extent of the author's knowledge, this law, does not speak specifically to siting guidelines for aquaculture or habitat protection, however, it was not fully available in English at the time of writing. The *Basic Environmental Law* (1993) does, however, set out general principles for environmental protection.

More specific aquaculture regulations are set out at the prefecture level of government and the regional fisheries coordination committees are responsible for administering aquaculture rights in their respective prefecture (Arsenault, Beigbeder, Johnson, & Pearce 2002). The committees are made up of fifteen members, with representatives from local fisherman, and other persons knowledgeable of the regional fishing industry. The application for an aquaculture right can be submitted only by a fisheries cooperative association and must include all the details of the proposed facility. If approved, the aquaculture right is valid for five years, after which another application is required for renewal. Given the regional scale at which aquaculture is managed and regulated in Japan, there is likely to be significant variation between the management regimes of the 47 prefectures that make up the country. The lack of information specifically applicable to aquaculture siting, on the one hand, raises concern about the effectiveness of regulation while, on the other hand, there is also no evidence to support the conclusion that the management regime is ineffective. Resultantly, this factor was scored moderately with a final score of 2.1 out of 10 namely due to the lack of transparency in monitoring and enforcement of set regulations.

Taiwan

The regulatory and management regime for aquaculture in Taiwan remains ill defined. The national Council of Agriculture hosts a fisheries agency (FA) branch, which in turn houses the Aquaculture Fisheries Division (AFD). The AFD is supposedly responsible for the planning, promotion, supervision and management of aquaculture (Fisheries Agency 2012), however, the acts and regulations that govern the Fisheries Agency and its divisions are heavily focused on capture fisheries and speak minimally to aquaculture. The *Fisheries Act* (1929, as amended) is one the most foundational pieces of legislation and it touches on aquaculture only briefly in Article 69, wherein it designates the municipality/county/city as the competent authority for the registration and management of inland aquaculture. Resultantly, it appears that the environmental protection bureaus (EPB), which are regional outposts of the Environmental Protection Administration (EPA), have overseen much of the aquaculture siting.

As per Article 17 in the *Standards for Determining Specific Items and Scope of Environmental Impact Assessments for Development Activities* (1995, as amended), an environmental impact assessment (EIA) is required for the construction of fish farms or fish ponds if the proposed site is: 1) located in a wildlife preserve or an important wildlife habitat environment, 2) located on a wetland, 3) located in a nature preserve, 4) located in an underground water control area, or 5) is expected to be greater than 50 hectares in size. The *Environmental Impact Assessment Act* (1994, as amended) and the *Environmental Impact Assessment Act Enforcement Rules* (1995, as amended) together outline the roles and responsibilities of the developer and central competent government authority as they pertain to carrying out an EIA. Neither of these outline standards specifically for aquaculture siting, nor do they speak to cumulative impacts of any industries. The *Environmental Impact Assessment Act* together with the *Basic Environment Act* (2002) provide legislative protection of high-valued environments and habitats.

It is unclear at this time how common it is for aquaculture sites to undergo an EIA. The EPA does report the total number of EIA cases accepted on an annual basis through the Taiwan Environment Data Warehouse, however, there are no details or descriptions of which industries the EIAs were conducted for. Given the lack of transparency in the enforcement process, it is unknown how effective the control measures and management regime is in mitigating the habitat impacts of aquaculture sitings. Over the past five years, records from the Taiwan Environment Data Warehouse show that 666 EIA cases were accepted, of which only seven were not approved and another 110 were approved with conditions. As mentioned in Criterion 2 for Taiwan, there have been many reports stating that the early years of aquaculture development came at significant environmental cost (Liao & Chao 2007, Liao 1998, Liao 2005, Chang 2010, Taiwan Review 2009, Wu 1999). Resultantly, the factors for assessing the regulatory and management effectiveness were scored conservatively and a final score of 0.875 (out of 10) was awarded.

<u>South Korea</u>

In South Korea, the *Fisheries Act* (1990, as amended) provides the basic regulatory framework for aquaculture in the country and requires that all persons cultivating seaweed, shellfish or other marine animals be licensed through the local government. All licenses are issued within the limits of fishing ground utilization and the development plan set out by the Ministry of Marine Affairs and Fisheries (MMAF) (FAO 2013*d*). The *Act on Assessment of Impacts of Works on Environment, Traffic, Disasters and Population* (1999) sets out the guidelines for which projects require EIAs, and outlines that these include projects that, *among other things,* result in the development of water resources and the cultivation and reclamation of public waters (FAO 2013*d*). This would suggest that aquaculture sites are required to undergo EIAs, however, there is no evidence or record to suggest that this has been done. A number of environmental protection legislations are in place—such as the *Wetlands Conservation Act* (1999), *Public Water Management Act* and the *Basic Environmental Policy Act* (1990)—which together protect high-value habitat (such as wetlands) from development. This industry's total size and future expansion does not appear to be limited, but, on the contrary, is generally being promoted at this time through the *Culture-Based Fishery Promotion Act* (2002) and the *Aquaculture Ground Management Act* (2000). The *Culture-Based Fisheries Promotion Act* (2002) requires the government to establish a framework that will promote culture-based fisheries every five years, but there is no evidence that either of these acts takes into consideration the cumulative effects of multiple farms. An aquaculture license is valid for typically ten years and upon expiration the license-holder must restore the area by removing all facilities installed.

The ministry responsible for fisheries in Korea has changed a number of times as of late. Originally the MMAF was the responsible ministry, however, in 2008 a reorganization of ministries saw the duties transferred to the Ministry for Food, Agriculture, Forestry and Fisheries, and, subsequently, in 2013 the Ministry of Oceans and Fisheries was established. Resultant of these changes, it is difficult to determine the enforcement process that is currently in place. Overall, the management and regulations in place to control habitat impacts of aquaculture siting in South Korea were found to be minimally effective and scored 1.2 out of 10.

Summary

The slight variability in management scores for the habitat criterion led to a range of final scores for Criterion C3. Overall, scores between 4.29 – 4.70 (out of 10) were awarded to the four countries because eel aquaculture in ponds was shown to have a low habitat conversion rate, however, the regulatory and management regimes in place are lacking in transparency and enforcement.

Criterion 4: Evidence or Risk of Chemical Use

Impact, unit of sustainability and principle

- *Impact: Improper use of chemical treatments impacts non-target organisms and leads to production losses and human health concerns due to the development of chemical-resistant organisms.*
- *Sustainability unit: non-target organisms in the local or regional environment, presence of pathogens or parasites resistant to important treatments.*
- *Principle: aquaculture operations by design, management or regulation avoid the discharge of chemicals toxic to aquatic life, and/or effectively control the frequency, risk of environmental impact and risk to human health of their use.*

Criterion 4 Summary

China and Taiwan

Chemical Use parameters	Score	
C4 Chemical Use Score	**0.00**	
C4 Chemical Use Final Score	**0.00**	**RED**
Critical?	NO	

Japan and South Korea

Chemical Use parameters	Score	
C4 Chemical Use Score	**4.00**	
C4 Chemical Use Final Score	**4.00**	**YELLOW**
Critical?	NO	

Brief Summary

The use of banned chemicals, most notably malachite green, is shown to occur in Chinese and Taiwanese eel aquaculture, resulting in a score of 0 out of 10 for these two countries. There is no evidence of such banned chemical use in Korea or Japan, however, there are demonstrably significant amounts of chemicals used in eel farming and the production systems employed, risking the release of said chemicals into the surrounding environment. The score for Korea and Japan is 4 out of 10.

Justification of Ranking

Two assessments are provided for this criterion as a result of demonstrable differences in the practice of chemical use between countries.

China and Taiwan

The use of chemicals such as nitrofurans, fluoroquinolones and malachite green in aquaculture have been prohibited by the Chinese authorities since 2002, however, eel exports containing these substances are still being reported with relative frequency. Since 2001, the US FDA continues to find residues of these and other chemical therapeutants in shipments of eel and related products from China[14] (FDA 2012). In 2005, the Korea Food & Drug Administration found malachite green in imported Chinese eel and related products (Gwang-lip 2005). Similar reports have been cited for eel imported into Japan from China in 2005, 2006 and 2007 (Mori, Nabeshima & Yamada 2013). In 2007, Japan went as far as to place restrictions on eel imports from China, due to the presence of malachite green, and Singapore now requires all eels and freshwater fish imported from China to undergo pre-export testing (Pandey 2005). Violations have been cited for the excessive use of sulfanilamide (Yu-Tzu, 2003), malachite green[15] (FDA, 2009) and nitrofurans for eel product sourced from Taiwan. (Hedlund 2006).

Several scientists have noted that despite the many laws, standards and policies in place to monitor chemical use in China, the efficiency of these regulations are weak due to the challenges of management, implementation and enforcement (Broughton & Walker 2010, Zhang 2007, Ming 2006, Tam & Yang 2005). Some of the major issues include: the uncoordinated nature of food regulations, the narrow scope of the laws (e.g., the regulatory framework does not consider the early stages of production, whereby banned pharmaceutical agents and other inputs could be in use), lax enforcement by inspectors, and minimal penalties issued for infringements. In Taiwan, although there are a number of regulations relating to water quality, the release of toxic substances, marine pollution, and specific regulations relating to the use of chemicals in aquaculture are not readily available. To that point, Liao & Chao (2007) noted that most inland aquaculture remains unregulated.

China and Taiwan have been noted to use a particularly high degree of chemical application in aquaculture due to the poor water quality resulting from sewage, industrial waste and agricultural runoff (including pesticides), as well as the increasing stocking density that has come with intensification of aquaculture practices (Chen, Lee & Lao 2007; Zhang 2007). Due to evidence of use of banned chemical substance in farmed aquaculture product (described above), China and Taiwan both received a score of zero (out of 10) for the Chemical Use criterion.

Korea and Japan

Both Japan and Korea have very low eel export volumes and, so far, none of these consignments have been rejected and/or detained for malachite green or other banned substances by the FDA or other regulatory bodies. Japan has a number of regulations to manage chemical use in aquaculture: Law to Ensure Sustainable Aquaculture Production (1999), Water Pollution Control Law (1970, as amended), Agricultural Chemicals Regulation Law (1948, as amended), Food Safety Basic Law (2003), Food Sanitation Law (1947, as amended). As such, there appears to be a certain degree of control over the use of banned chemicals and substances (FAO 2013*c*). For Korea, only limited information was available on the use chemicals and veterinary drugs used by the aquaculture industry (FAO 2013*d*, Joh et al. 2011, Joh et al.

[14] http://www.accessdata.fda.gov/cms_ia/importalert_33.html
[15] http://www.accessdata.fda.gov/cms_ia/importalert_27.html

2007). Applicable legislations that are believed to regulate chemical use in the aquaculture industry include the Culture-Based Fishery Promotion Act (2002), the Public Water Management Act (1961, as amended), the Water Quality Conservation Act (1990, as amended), and the Fishery Products Quality Control Act that came into effect 1 September 2001 (FAO 2013*d*). The latter regulation was developed to improve food safety and harmonize with international standards of food quality.

Both Japan (Usiui 1974, Miyai 2004) and Korea (Joh et al. 2011, Joh et al. 2007) have documented outbreaks of diseases relating to pond systems and their external environment. Eels in particular are known to be prone to parasites such as *Heterosporis anguillarum* (Joh et al. 2007). As both countries employ predominantly outdoor pond and flow-through systems for eel farming, there remains great potential for chemicals and antibiotics to be released to the environment. Resultantly, Korea and Japan received a score of 4 because the production method and history of disease outbreaks suggest that a significant amount of chemicals are used in eel farming and the production systems employed risk the release of these chemicals into the surrounding environment.

Criterion 5: Feed

Impact, unit of sustainability and principle

- *Impact: feed consumption, feed type, ingredients used and the net nutritional gains or losses vary dramatically between farmed species and production systems. Producing feeds and their ingredients has complex global ecological impacts, and their efficiency of conversion can result in net food gains, or dramatic net losses of nutrients. Feed use is considered to be one of the defining factors of aquaculture sustainability.*
- *Sustainability unit: the amount and sustainability of wild fish caught for feeding to farmed fish, the global impacts of harvesting or cultivating feed ingredients, and the net nutritional gains or losses from the farming operation.*
- *Principle: aquaculture operations source only sustainable feed ingredients, convert them efficiently and responsibly, and minimize and utilize the non-edible portion of farmed fish.*

Criterion 5 Summary

Feed parameters	Value	Score	
F5.1a Fish In: Fish Out ratio (FIFO)	1.12	7.20	
F5.1b Source fishery sustainability score		-6.00	
F5.1: Wild Fish Use		6.53	
F5.2a Protein IN	15.83		
F5.2b Protein OUT	10.62		
F5.2: Net Protein Gain or Loss (%)	-32.94	6	
F5.3: Feed Footprint (hectares)	22.96	2	
C5 Feed Final Score		**5.26**	**YELLOW**
Critical?	NO		

Brief Summary

Eel farming in Asia utilizes a commercial feed with high levels of fishmeal, 84% of which is derived from processing byproducts as opposed to whole fish. Eel feeds contain 4% fish oil inclusion and the eFCR of the industry is shown to be 1.4:1. Eel farming is shown to result in a 32.9% net loss of protein. A total ocean and land area of 22.96 hectares is calculated to be necessary to produce the feed ingredients required to grow one ton of farmed eel. The numerical score for Criterion 5 – Feed is 5.26 out of 10.

Justification of Ranking

Note that for this criterion, if a range of values is reported in the literature, the median value was applied in the assessment to ensure typical farming practices were represented.

Factor 5.1. Wild Fish Use

With the intensification of eel aquaculture, it has become common practice to provide high-energy, protein-rich, commercial feeds through all culture phases (Ottolenghi et al. 2004). In the grow-out phase, feeds are delivered as paste, dough or pellets. Feeds typically have a high protein content, ranging from 45% (Weimin & Mengqing 2007) to 50% (FAO 2013). The high protein content is derived predominantly from fishmeal, for which inclusion levels range between 55% (Tacon & Metian 2008) and 62% (Weimin & Mengqing 2007). The report by Weimin & Mengquing (2007) includes a “practical feed formulation for eel” that was provided by a feed producer from the Guangdong province of China, in which 84% of the fishmeal is sourced from byproduct. China is one of the main eel feed producers with over 100 feed mills that produce over 350,000 tons of feed (Weimin & Mengquing 2007), however, given the volatility in sources of fishmeal, it is uncertain how common the practice is to include such a high degree of fishmeal byproduct. Despite this uncertainty, this value was used in the assessment, as there was no evidence or data to counter it. Fish oil inclusion rates in eel feed are relatively low ranging from 3.5% to 5% (Tacon and Metian 2008); a fish oil inclusion level of 4% was utilized in the assessment.

Ottolenghi et al. (2004) reported that the feed conversion ratio (FCR) for Asian and European intensive eel farming operations ranged from 0.9 to 1.9:1. To date, there appear to have been few advances in improving the FCR efficiency, as a more recent report by Krikegaard (2010) stated that typical FCRs in European culture were between 1.6 and 1.7:1. Tacon & Metian (2008) provide the most specific estimates of FCRs in Asia, whereby they report an FCR of 1.4 in Korea and 1.7 in Taiwan. This latter report also goes on to estimate that in 2010 the average FCR for eel farming would be 1.4. An FCR value of 1.4 was applied to all calculations herein as it the average value of all those found in the literature.

Applying the figures above, FIFO ratio was calculated to be 0.58 for fishmeal and 1.12 for fish oil, which scores 7.20 out of 10 in the Seafood Watch methodology. A FIFO of 1.12 means that from first principles, 1.12 tons of wild fish would need to be caught and processed to supply sufficient fish oil to grow one ton of farmed salmon in land-based closed containment recirculating aquaculture systems.

An adjustment score can be applied based on the relative sustainability of the source fisheries from which fishmeal and fish oil are derived. Given the globalization of the fishmeal industry, lack of traceability through supply chains and the major role that Asia plays in commercial feed production, the source fisheries for fishmeal and fish oil are unknown. According to the Seafood Watch criteria, an adjustment score of -6 out of -10 is applied for the unknown sustainability of the source fisheries.

When the adjustment score is applied, the resulting numerical score for Factor 5.1 is 6.53.

Factor 5.2. Net Protein Gain or Loss

Applying the data provided by Weimin & Mengquing (2007) in the “practical feed formulation for eel,” it was found that 67% of protein in the feed was from nonedible sources (fishmeal byproduct), while the remaining 33% were sourced from edible crops such as fishmeal, soybean and cassava starch.

Typical protein content of whole harvested eel ranges from 14% to 17% (Heinsbroek et al. 2007, FAO 2001), while the edible yield rate can range from 60% to 75%, depending on the processing method (Crapo et al. 1993, Venugopal 2005).

Overall, these values are used in a series of calculations (see Appendix 1) that conclude that eel farming results in a net protein loss of 32.9%. This loss corresponds to a numerical score of 6 out of 10 for Factor 5.2.

Factor 5.3. Feed Footprint

According to the feed formulation in the report by Weimin & Mengquing (2007), no land animal products are included in commercially produced eel feeds. Personal communications with representatives from BioMar and Skretting, two of the leading producers of eel feed in Europe, also claim to have a zero percent inclusion of land animal products. Aside from the high degree of marine resource inclusion (fishmeal and fish oil combined represent 62.5% of feed ingredients), the remainder of formulated eel feeds (37.5%) is made up of crop feed ingredients such as wheat, soy, and/or cassava. These values were utilized in the calculation to determine that the production of one metric ton of farmed eel requires the appropriation of 22.76 hectares of ocean area and 0.20 hectares of land area (see Appendix 1 for calculations). This 22.96-hectare feed footprint corresponds to a score of 2 out of 10.

Summary

The scores for Factors 5.1, 5.2 and 5.3 are combined to result in a final Criterion 5 – Feed score of 5.26 out of 10. This score is driven by the moderate degree of wild fish use in eel feed, the net protein loss that occurs in eel farming, and the relatively high feed footprint resulting from the large area of ocean appropriated for feed production.

Criterion 6: Escapes

Impact, unit of sustainability and principle

- *Impact: competition, genetic loss, predation, habitat damage , spawning disruption, and other impacts on wild fish and ecosystems resulting from the escape of native, non-native and/or genetically distinct fish or other unintended species from aquaculture operations.*
- *Sustainability unit: affected ecosystems and/or associated wild populations.*
- *Principle: aquaculture operations pose no substantial risk of deleterious effects to wild populations associated with the escape of farmed fish or other unintentionally introduced species.*

Criterion 6 Summary

Escape parameters	Value	Score	
F6.1 Escape Risk		2.00	
F6.1a Recapture and mortality (%)	0		
F6.1b Invasiveness		4	
C6 Escape Final Score		**3.00**	**RED**
Critical?	NO		

Brief Summary

Eel farming ponds have high daily water exchange rates and inherent connectivity to natural water bodies. No evidence exists of recapture or direct mortality of escapees. Though non-native eels are cultured throughout Asia and have been encountered in the wild, the scientific evidence suggests that they are not established and are unlikely to establish viable populations.

Justification of Ranking

Factor 6.1a. Escape risk

Eels in Asia are cultured primarily in a variety of pond systems (greenhouse, still and/or flow-through). These systems typically have high flushing rates ranging from 15% to 35% water exchange per day (Heinsbroeck 1991, Nielsen & Prouzet 2008); the Seafood Watch criteria classify these systems as a moderate-high escape risk due to inherent connectivity to natural water bodies. Each of the countries included in this assessment have basic environmental legislation and/or fisheries laws that speak to the importance of protecting wild native species, but no specific legislation or best management practices could be found with respect to minimizing the escape of species from aquaculture systems. Each of the countries included here also have legislation governing the import of exotic species, however, these regulations speak almost exclusively to minimizing the risk of disease transfer upon entry of the exotic species.

It may be possible that best management practices specific to minimizing aquaculture escapes do exist and simply are not available to the author due to language barriers, however, the growing number of reports of escaped non-native eel species in Japan, China and Taiwan (see Factor 6.1b) suggest that, even if best management practices are in place, they are not effective at this time.

The initial escape risk score is 2 out of 10. This score may be adjusted upward if evidence exists of recapture or direct mortality of escapees. No such evidence was available at the time of this report and, as such, no recapture/mortality adjustment is applied and the numerical score for Factor 6.1 is 2 out of 10.

Factor 6.1b. Invasiveness

As a result of inconsistent availability of *A. japonica* glass eels, it has become common practice for eel aquaculturists in Asia to source non-native glass eels and elvers (particularly European eels (*A. anguilla*) and American eels (*A. rostrata*)) for grow-out (Crook et al. 2010, Casselman & Cairns 2009, Ottolenghi 2004). Due to the lack of species-specific labeling of eel products through the complex international trade system, it is not possible at this time to identify what proportion of current farmed stock is of native or non-native species. The recent listing of *A. anguilla* in Appendix II of CITES is anticipated to decrease the amount of European eel being farmed in Asia, however, some have speculated that this will in turn increase the import of other non-native species (*A. rostrata, A. australis*, *A. bicolor*, and *A. mossambica*) because recent catches of *A. japonica* glass eel are simply not sufficient to supply the demand (Crook 2010, Miller and Casselman, in press). Although non-native species do not represent 100% of the current farmed stock in Asian eel aquaculture, there is sufficient evidence to suggest that non-native eel species are commonly cultured (Crook, pers. comm.; Ringuet et al. 2002). Due to the inconsistency of reporting production statistics and import/export data to a species-specific level (i.e., most data is simply recorded as *Anguilla sp.*), it is not possible to determine what percentage of stock may be native versus non-native. As such this factor has been scored for stock that is non-native as this represents a realistic worst-case scenario.

The academic literature contains several examples of non-native eel species being encountered in the wild across Asia. Han et al. (2002) reported the first identification of exotic eels in Taiwan in 2002 when six American eels (*A. rostrata*) were found in the Kaoping River. Additionally, a Japanese survey conducted in 2000 found that European eels accounted for 93.5% of the 98 specimens sampled in the Uono River (Aoyama et al. 2000). A more comprehensive survey was conducted in Japan in 2006 and it was found that only 6.8% of the eels collected from 16 sites in Japan were European eels (Okamura et al. 2007). Many of the captured non-native European eels had metamorphosed into migratory silver eels suggesting they had the ability to initiate spawning, however, the researchers concluded that it was unlikely for them to establish due to the observed decline in European eel presence at these sites (Okamura et al. 2007). It is uncertain how successful non-native eel species will be at self-propagating in Asian waters, but many have suggested that the potential for these species to establish new spawning grounds in Asia cannot be overlooked (Han et al. 2002, Aoyama et al. 2000). As such, the current non-native farmed stock is deemed to be present in the wild but not established and not likely to establish viable populations (score of 1.5 out of 2.5 for Factor 6.1b Part B).

The ongoing escape of non-native eel species from culture ponds presents a moderate to high impact for the natural ecosystem, as escapees have been documented to compete with wild native populations for food and habitat and may act as additional predation pressure for some prey (Aoyama et al. 2000, Okamura et al. 2007). There is no evidence at this time that non-native eel species have interbred with the native Japanese eel, however both Okamura et al. (2007) and Han et al. (2002) note that there is potential for interspecific hybridization should non-native eel species begin to spawn in the Mariana Islands which is the natural spawning ground for the native Japanese eel. The life history and nature of non-native eel species do not differ greatly from that of native eel species and as such escapees are not anticipated to modify habitats to the detriment of other species. Part C in Factor 6.1b scored 2.5 out of 5 because escaped eel from aquaculture sites in Asia pose a moderate invasiveness risk to natural ecosystems. When the score for Parts B and C are combined, the numerical score for Factor 6.1b is 4 out of 10.

Overall, the impact, or risk of impact, of escapes from eel culture ponds in Asia was determined to be high. Criterion 6 – Escapes receives a numerical score of 3 out of 10 and is driven by a moderate-high escape risk and a moderate invasiveness score.

Criterion 7: Disease; pathogen and parasite interactions

Impact, unit of sustainability and principle

- *Impact: amplification of local pathogens and parasites on fish farms and their retransmission to local wild species that share the same water body.*
- *Sustainability unit: wild populations susceptible to elevated levels of pathogens and parasites.*
- *Principle: aquaculture operations pose no substantial risk of deleterious effects to wild populations through the amplification and retransmission of pathogens or parasites.*

Criterion 7 Summary

Pathogen and parasite parameters	Score	
C7 Biosecurity	2.00	
C7 Disease; pathogen and parasite Final Score	**2.00**	**RED**
Critical?	**NO**	

Brief Summary

A variety of pathogens and diseases occur on eel farms in Asia and result in mortalities of farm stock. The pond production systems exhibit high daily water exchange rates (10-35% per day according to Nielsen and Prouzet 2008) and present a high concern for release of pathogens into the surrounding environment. The numerical score for Criterion 7 – Disease is 2 out of 10.

Justification of Ranking

Disease, particularly of bacterial origin, is a major cause of economic loss in the eel aquaculture industry (Joh et al., 2013). Some of the common pathogens include *Edwardsiella tarda* (Chen & Kou, 1992; Joh et al., 2011), *Listonella anguillarum* (Austin & Austin, 1999), *Vibriovulnificus serovar* (Hoi, Dalsgaard, DePaola, Siebeling, & Dalsgaard 1998; Austin & Austin, 1999), *Aeromonas hydrophila* (Hah, Hong, Oh, Fryer, & Rohovec, 1988; Yoo, Kwon, Yoon, Park, & Choi, 1990), and *Pseudomonas anguilliseptica* (Haenen & Dvvidse, 2001; Berthe, Michel, & Bernadette, 1995).

Many of these diseases are believed to thrive when environmental conditions are unbalanced, such as high water temperature, poor water quality and high organic content, which are common in pond culture systems (Wang, Zhang, & Austin, 2010). Some of the diseases seen in eel aquaculture, such *E. tarda* and some *Aeromonas spp*., pose a direct risk to human health as they are known human pathogens that can cause gastrointestinal and extra-intestinal infections (Janda & Abbott, 1993; Gutierrez et al., 1993). Due to this risk of transferability, particular attention should be given to prevent risk factors associated with *E. tarda* infections in humans (Joh et al., 2011; Joh et al., 2013).

There is also growing evidence that many eel diseases can affect multiple species and may be easily transferred across geographic regions. For example, the parasite *Anguillicoloides crassus* and the swim-bladder nematode (*A. globiceps*), are known to affect farmed and wild populations of both Japanese European eels (Ottolenghi et al., 2004). Outbreaks of *A. crassus* occurred in Europe (Molnár, Székely, & Baska, 1991) and North America (Barse & Secor, 1999) in the 1980's, which were found to originate from Japanese eels that were imported live from Asia for aquaculture. More recently *A.* crassus has also been found in eels in the St. Lawrence River System in Canada (Casselman, unpublished data).

<u>China</u>

Examples of pathogens and parasites impacting Chinese eel aquaculture include *E. tarda*, which has caused mortalities in Chaozhou, Guangdong Province (Quanzhang & Xinling, 1994) and the parasite *A. crassus* (Ottolenghi et al., 2004). A recent study on bacterial diversity in coastal mariculture farms of Southeast China (Zeng et al., 2010) found evidence of pathogenic entities including *Escherichia, Aeromonas, Bacillus* and *Vibrio* (Zeng et al., 2010). The study also found high quantities of the antibiotic streptomycin in some of the water samples, and the authors indicate that there is a risk that bacteria, such as *Vibrio sp*., are becoming resistant to this drug (Zeng et al., 2010). In addition to causing diseases within cultured ponds, this bacterium could also negatively affect the natural composition of bacteria in the surrounding environments (Zeng et al., 2010).

<u>Japan</u>

Several viral, bacterial, fungal, and other parasitic diseases have been reported in Japanese eel farms including *Saprolegnia* fungal infection caused by a pathogenic bacterium (Lee, Nomura & Miyazaki, 1999), and *Edwardsiellosis*, caused by *E. tarda* (Hoshina, 1962). Other Introduced pathogens include the parasitic nematode *Ichthyophthirius multifilis* (Oka, & S. Egusa, cited in Münderle et al., 2006), the brachial trematode, *Gyrodactylus anguillae* (Ogawa & Egusa, 1980), and the fungus, *Dermocystidium anguillae* (Hatai, Hirose, Hioki, Miyakawa & Egusa, 1979). It has been suggested that the ongoing documentation of non-native eel species in Japanese waters is likely due to escaped stock from production ponds (Aoyama, Watanabe, Ishikawa, Nishida, & Tsukamoto, 2000; Okamura et al. 2008), which highlights this as an important introduction pathway for diseases to the natural environment (Miyai et al., 2004).

<u>Taiwan</u>

In addition to earlier mentioned pathogens and bacterium, other parasites recorded at Taiwanese eel aquaculture sites include *Pleistophora anguillarum* (Kou & Lou, 1994), enteritis type bacterial diseases, fungal diseases, gill diseases, and diseases caused by water quality, deformity, nutritional disease, and drug injuries which evolve into diseases (Shih, Lu & Chen, 1993). Infectious Pancreatic Necrosis Virus (IPNV) (Hsu, Chen & Wu 1993) and Eel Herpesvirus in Formosa (EHVF) are also found in Taiwanese cultured eels (Ottolenghi, 2004). Additionally, as observations of non-endemic European eels (*Anguilla* anguilla) in the wild become more common (likely due to escapes from eel farms), there is an increased risk that new and/or foreign pathogens may be introduced. Some studies, for example, have indicated that European eels appear to be more susceptible to *Anguillicoloides crassus* than the Japanese eel (Münderle et al., 2006).

South Korea

There have been several reports of *E. tarda*, *A. hydrophila*, and *Vibrio spp*. in Korean eel aquaculture (Hah et al., 1984; Yoo et al., 1990; Kim, Ok, Kim, & Oh, 2011; Joh et al., 2011). A study conducted between 2003 and 2010 on 621 diseased eels from 26 eel farms supported earlier research in that *E. tarda* was one of the most important bacterial pathogens in eels (Joh et al., 2011). This study also noted that the infection rates varied greatly from farm to farm, indicating a wide variation in the sanitary management of farms (Joh et al., 2011). Infections caused by the parasite *Heterosporis anguillarum* have caused significant economic losses in Korea and elsewhere, as the transmission rate within ponds is high (Suh & Chun, 1998, cited in Joh et al., 2007). As pathogenic risk to cultured eels both in South Asia and internationally is high, it is recommended that this specific parasite be consistently monitored with continual stringent management of production systems (Joh et al., 2007)

Summary

Overall, the relative frequency with which diseases are reported in each of these four countries suggests that pathogens are of significant concern in eel farming operations. The nature of the production systems employed (pond and/or flow-through) allow for significant amounts of water to be released into the natural environment, suggesting that introduction of pathogens or disease from farm sites is likely. This is of particular concern in the case of eel farming because wild Japanese eel stocks are currently considered threatened and the risk of transferring diseases and pathogens may place further stress on these stocks. There is, however, no evidence at this time that eel aquaculture is actually resulting in an amplification of pathogens and parasites in the natural environment. As a result, Criterion 7 – Disease scores 2 out of 10.

Criterion 8: Source of Stock – independence from wild fisheries

An interim update of this assessment was conducted in July 2021. This criterion was updated with new information. The interim update can be found in Appendix 2 at the end of this document.

Impact, unit of sustainability and principle

- *Impact: the removal of fish from wild populations for on-growing to harvest size in farms*
- *Sustainability unit: wild fish populations*
- *Principle: aquaculture operations use eggs, larvae, or juvenile fish produced from farm-raised broodstocks thereby avoiding the need for wild capture*

Criterion 8 Summary

Source of stock parameters	Score	
C8 % of production from hatchery-raised broodstock or natural (passive) settlement	0	
C8 Source of stock Final Score	**0.00**	**RED**

Brief Summary

Despite significant research efforts, eels are unable to be hatched and raised in hatcheries. All eels grown by the aquaculture industry are sourced from wild populations, and as such the industry is completely dependent on wild stocks. As such, Criterion 8 – Source of Stock scores 0 out of 10.

Justification of Ranking

Despite significant efforts in research since the 1930s, there has been little success in closing the lifecycle and raising any of the *Anguilla* species in hatcheries. In 1974 Yamamoto and Yamauchi were the first researchers to successful obtain fertilized eggs and larvae from the Japanese eel using hormone treatments, however the larvae did not survive past a two-week rearing period (Tanaka et al, 2003). Since this time, artificial sexual maturation has been induced in *A. anguilla, A. rostrata, A. dieffenbachii* and *A. australis* to obtain eggs and larvae, but no further development has been successful (Minegishi et al., 2012). The Japanese eel (*A. japonica*) has seen the greatest achievements to date whereby in 2003 Tanaka et al successfully reared larvae into the glass eel stage. This success appears to be most attributable to advances in developing a specialized diet that support the larvae beyond the depletion of their yolk and oil droplet stores in the preleptocephalus larvae stage (Tanaka et al. 2003). Although this study was determined to be a huge advance in the domestication of eels, many challenges still persist including high mortality rates, reduced growth rates, and the inability to date to foster spontaneous gametogenesis and spawning in captivity (Tanaka et al., 2003; Minegishi et al., 2012).

Due to the ongoing challenges in the domestication of eel, the aquaculture industry remains fully reliant on wild-caught brood stock and hence Criterion 8 – Source of Stock scores 0 out of 10.

Criterion 9X: Wildlife and predator mortalities

A measure of the effects of deliberate or accidental mortality on the populations of affected species of predators or other wildlife.

This is an "exceptional" criterion that may not apply in many circumstances. It generates a negative score that is deducted from the overall final score. A score of zero means there is no impact.

Criterion 9X Summary

Wildlife and predator mortality parameters	Score	
C9X Wildlife and predator mortality Final Score	**-6.00**	**Yellow**
Critical?	NO	

Brief Summary
While no information on wildlife interactions with eel ponds was available for analysis, it is reasonable to presume interactions do occur. As no further data on wildlife mortalities, species status, or population-level impacts are available, this Exceptional Criterion is scored on a precautionary basis according to the Seafood Watch criteria and results in an adjustment score of -6 out of -10.

Justification of Ranking
The high density of fish in outdoor pond culture systems presents a prime foraging opportunity for wildlife and predators. It has been repeatedly noted, for example, that water birds will forage at aquaculture sites (Ma 2011, Ma 2004, Price 1995) to the extent that the year-round food supply provided by extensive aquaculture systems may even cause behavioral and migration pattern changes (Tucker, Hargreaves & Boyd 2008). No information could be found, at the time of this writing, on the exclusion practices used by fish farmers in any of the four countries included in this report, nor is there any evidence of direct or incidental mortalities of predators on aquaculture sites. However, it is presumed that wildlife and predators do interact with eel ponds and, as such, some level of mortality is reasonable to expect. As the species status or impacts at the population level are unknown, a score of -6 out of -10 is applied to this Exceptional Criterion.

<u>Criterion 10X: Escape of unintentionally introduced species</u>

A measure of the escape risk (introduction to the wild) of alien species <u>other than the principle farmed species</u> unintentionally transported during live animal shipments.

This is an "exceptional" criterion that may not apply in many circumstances. It generates a negative score that is deducted from the overall final score.

Criterion 10X Summary

Escape of unintentionally introduced species parameters	Score	
F10Xa International or trans-waterbody live animal shipments (%)	0.00	
F10Xb Biosecurity of source/destination	2.00	
C10X Escape of unintentionally introduced species Final Score	**-8.00**	**RED**

Brief Summary
Eel aquaculture relies heavily on international and trans-waterbody shipment of animals. As juvenile eels are sourced from wild populations, the biosecurity of the source is considered negligible and an area of high concern as other species besides eels have the potential to be caught and transported with the juvenile eels. The biosecurity of the source ponds is also a high concern as high daily water exchange rates create the potential for the release of an unintentionally introduced species. The numerical score for the Exceptional Criterion 10X is -8 out of -10.

Justification of Ranking

Factor 10Xa International or trans-waterbody live animal shipments
Eel aquaculture is completely dependent on wild-caught glass eels and elvers for the farm stock (FAO 2013*e,* Crook 2010, Casselman & Cairns 2009). Historically, eel farming was mostly carried out using species of local provenance, but, as previously noted, the inconsistent supply of local species led to the development of international trade in glass eels of many different *Anguilla* species. Given the significant challenges observed with traceability and labeling of eel products, it is not possible at this time to determine what proportion of eel farmed in Asia is dependent on international or trans-waterbody live animal shipments. However, the declining wild stocks of the local eel species (*A. japonica*) suggest, that a realistic worst-case scenario would be that more that 90% of the farmed stock would be reliant on international or trans-waterbody live animal shipments. As such, the score for Factor 10Xa is 0 out of 10.

Factor 10Xb Biosecurity of source/destination
In the case of the eel aquaculture industry, there is a heavy reliance on international or trans-waterbody live animal shipments for glass eels and elvers, which are stocked for growout in aquaculture ponds. Glass eels and elvers are harvested from the wild where no biosecurity measures exits, and therefore the biosecurity score of the source of animal movements is of

high concern and received a score of 0. The biosecurity score of the destination is of moderate-high concern and received a score of 2 because eel aquaculture in Asia is predominantly carried out in pond systems (greenhouse, still, or flow-through) with daily water exchange rates between 10% and 35% per day (Nielsen & Prouzet 2008).

Overall, this criterion received a score of -8 due to the high dependency on international (or trans-waterbody live animal shipments) and high biosecurity concerns of both the source and destination of the animal shipments.

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Scientific review does not constitute an endorsement of the Seafood Watch® program, or its seafood recommendations, on the part of the reviewing scientists. Seafood Watch® is solely responsible for the conclusions reached in this report.

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References

Agricultural Resource Marketing Center. (2013). *American eel*. Retrieved from http://www.agmrc.org/commodities__products/aquaculture/american-eel/

Arsenault, M., Beigbeder, T., Johnson, N., & Pearce, K. (2002). *Current and Future Regulation of Marine Aquaculture*. National Oceanic and Atmospheric Administration, National Sea Grant Program. Retrieved from http://www.lib.noaa.gov/retiredsites/docaqua /wpiprojects/currentrept.htm

Aoyama, J., Watanabe, S., Miyai, T., Sasai, S., & Nishida, M. (2000). The European eel, Anguilla anguilla (L.), in Japanese waters. *Dana, 12*, 1–5.

Austin, B., Austin, D.A., (1999). *Vibrionaceae* representatives. In: *Bacterial Fish Pathogens*, 3rd ed. Springer, London, pp. 270–276.

Barse, A. M., & Secor, D. H. (1999). An exotic nematode parasite of the American eel. *Fisheries, 24(2)*, 6-10.

Berthe, F., Michel, C., & Bernadette, F. (1995). Identification of Pseudomonas anguilliseptica isolated from several fish species in France. *Dis. Aquat. Org. 21*, 151– 155.

BioMar. (2013). Dan-Ex 2848 eel. Retrieved from http://www.biomar.com/Countries/ common%20ceu/Datasheets/Datasheets%20Baltic/Eel-Aal%20Baltic/English_Eel /EN%20DAN-EX%202848%201,5-2-3mm%20eel.pdf?epslanguage=en

Broughton, E.I. and D.G. Walker. (2010). Policies and practices for aquaculture food safety in China. *Food Policy* 35: 471-478.

Cao, L., Wang, W., Yang, Y., Yang, C., Yuan, Z., Xiong, S., & Diana, J. (2007). Environmental impact of aquaculture and countermeasures to aquaculture pollution in China. *Environmental science and pollution research international*, *14*(7), 452–62. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/18062476

Casselman, J.M. and Cairns, D.K. (2009). *Eels at the Edge: Science, Status and Conservation Concerns.* Symposium 58. American Fisheries Society. 449pp.

Chang, H.-H., Boisvert, R. N., & Hung, L.-Y. (2010). Land subsidence, production efficiency, and the decision of aquacultural firms in Taiwan to discontinue production. *Ecological Economics*, *69*(12), 2448–2456. doi:10.1016/j.ecolecon.2010.07.020

Chen, J.-D., Kou, G.-H., 1992. *Studies on bacteria distribution in pond cultured eels*. COA Fish 10, 25–42.

Chen, Y. H., Lee, W. C., & Liao, I. C. (2007). Sustainable development of eel aquaculture industries in Taiwan and mainland China. In P. Leung, C. Lee & P. O'Bryen (Eds), *Species and System Selection for Sustainable Aquaculture* (pp.295-312). Blackwell Publishing, Iowa, US.

Crapo, C., Paust, B., & Babbitt, J. (1993). *Recoveries & yields from Pacific fish and shellfish*. Alaska Sea Grant College Program Marine Advisory Bulleting, 37. Retrieved from http://nsgl.gso.uri.edu/aku/akug93001.pdf

Crook, V. (2010). *Trade in Anguilla species, with a focus on recent trade in European eel A. anguilla*. *TRAFFIC* report prepared for the European Commission.

Crook, V., and M. Nakamura. 2013. Glass eels: Assessing supply chain and market impacts of a CITES listing on *Anguilla* species. TRAFFIC Bulletin Vol. 25 No. 1, 7 pages.

Environmental Protection Administration (EPA). 2010. Historical development and background. Retrieved from pashow.aspx?list=9044&path=9055&guid=da6d766e-4053-4dc9-896d-c85421f2b5b6&lang=en-us

Food and Agriculture Organization (FAO). (2001). *Information on Fisheries Management in the People's Republic of China*. Retrieved from http://www.fao.org/fi/oldsite/FCP/en/CHN/body.htm

Food and Agriculture Organization (FAO). (2013*b*). National aquaculture legislation overview – China. Retrieved from http://www.fao.org/fishery/legalframework /nalo_china/en

Food and Agriculture Organization (FAO). (2013*a*). FishStatJ. Available from http://www.fao.org/fishery/statistics/software/fishstatj/en

Food and Agriculture Organization (FAO). (2013*c*). National aquaculture legislation overview – Japan. Retrieved from http://www.fao.org/fishery/legalframework/ nalo_japan/en

Food and Agriculture Organization (FAO). (2013*d*). National aquaculture legislation overview – Republic of Korea. Retrieved from http://www.fao.org/fishery /legalframework/nalo_korea/en#tcNB00CB

Food and Agriculture Organization (FAO). (2013*e*). Cultured aquatic species information pogramme – *Anguilla japonica*. Retrieved from http://www.fao.org/fishery/culturedspecies/Anguilla_japonica/en

Fisheries Agency of the Council of Agriculture Republic of China. *Aquaculture Fisheries Division*. Retrieved from http://www.fa.gov.tw/en/AbFaMission/content.aspx?id =4&chk=11abb6d7-5957-452f-9643-a48325f3f1c1&param=pn%3d1

Gutierrez, M. A., Miyazaki, T., Hatta, H., & Kim, M. (1993). Protective properties of egg yolk IgY containing anti-*Edwardsiella tarda* antibody against paracolo disease in the Japanese eel, *Anguilla japonica* Temminck & Schlegel. *Journal of Fish Diseases, 16(2),* 113-122.

Gwang-Lip, M. (2005, July 27). KFDA bans Chinese eels containing carcinogen. *The Korea Times*. Retrieved from http://www.houblon.net/spip.php?article2344

Haenen, O.L.M & Dvvidse, A., (2001). First isolation and pathogenicity studies with *Pseudomonas anguilliseptica* from diseased European eel *Anguilla anguilla* (L.) in The Netherlands. *Aquaculture 196*, 27–36.

Hah, Y.C., Hong, S.W., Oh, H.B., Fryer, J.L., Rohovec, J.S., (1984). Isolation and characterization of bacterial pathogens from eels (*Anguilla japonica*) cultured in Korea. *Kor. J. Microbiol. 22 (1)*, 41–48.

Hall, S.J., Delaporte A., Phillips, M.J., Beveridge M., & O'Keefe, M. (2011). *Blue Frontiers: Managing the Environmental Costs of Aquaculture*. Malaysia: The WorldFish Center.

Halpin, P. (2007). Seafood Watch Seafood Report – Unagi. Retrieved from http://www.montereybayaquarium.org/cr/cr_seafoodwatch/content/media/MBA_SeafoodWatch_UnagiReport.pdf

Han, Y. (2002). The exotic American eel in Taiwan: ecological implications. *Journal of Fish Biology*, *60*(6), 1608–1612. doi:10.1006/jfbi.2002.2022

Hatai K., Hirose H., Hioki M., Miyakawa M. & Egusa S. (1979) Dermocystidium anguillae found on the gills of the European eel, *Anguilla anguilla* cultured in Japan. *Fish Pathology 13,* 205–210.

Hedlund S. (2006, June 1). Don't let malachite green put you in the red. *Seafood Business Magazine*. Retrieved from http://www.seafoodbusiness.com/articledetail.aspx?id=4294995758

Heinsbroek, L.T.N. (1991). A review of eel culture in Japan and Europe. *Aquaculture and Fisheries Management, 22*, 57-72.

Heinsbroek, L. T. N., Van Hooff, P. L. a., Swinkels, W., Tanck, M. W. T., Schrama, J. W., & Verreth, J. a. J. (2007). Effects of feed composition on life history developments in feed intake, metabolism, growth and body composition of European eel, Anguilla anguilla. *Aquaculture*, *267*(1-4), 175–187. doi:10.1016/j.aquaculture.2007.03.028

Hoi, L., Dalsgaard, I., DePaola, A., Siebeling, R.J., & Dalsgaard, A. (1998). Heterogeneity among isolates of Vibrio vulnificus recovered from eels (*Anguilla anguilla*) in Denmark. *Appl. Environ. Microbiol. 64*, 4676– 4682.

Hoshina, T (1962). Studies on red-fin disease of eel. *Journal of the Tokyo University of Fisheries 6*(1), 105

Hsu, Y. L., Chen, B. S. & Wu, J.L. (1993). Demonstration of infectious pancreatic necrosis virus strain VR-299 in Japanese eel, *Anguilla japonica* Temminck & Schlegel. *Journal of Fish Diseases, 16:123-129*.

Janda, J.M., & Abbott, S.L., (1993). Infections associated with the genus Edwardsiella: the role of E*dwardsiella tarda* in human disease. *Clinical Infectious Diseases 17*, 742–748.

Joh, S. J., Ahn, E. H., Lee, H. J., Shin, G. W., Kwon, J. H., & Park, C. G. (2013). Bacterial pathogens and flora isolated from farm-cultured eels (*Anguilla japonica*) and their environmental waters in Korean eel farms. *Veterinary microbiology*, 163, 190–195

Joh, S.J., Kim, M.J., Kwon, H.M., Ahan, E.H., Jang, H., Kwon, J.H. (2011). Characterization of *Edwardsiella tarda* isolated from farm-cultured eels Anguilla japonica in Korea. *J. Vet. Med. Sci. 73, 7–11*.

Joh, S. J., Kwon, Y. K., Kim, M. C., Kim, M. J., Kwon, H. M., Park, J. W., ... & Kim, J. H. (2007). Heterosporis anguillarum infections in farm cultured eels (Anguilla japonica) in Korea. *Journal of veterinary science, 8(2)*, 147-149.
Joh, S. J., Kwon, Y. K., Kim, M. C., Kim, M. J., Kwon, H. M., Park, J. W., ... & Kim, J. H. (2007). Heterosporis anguillarum infections in farm cultured eels (Anguilla japonica) in Korea. *Journal of veterinary science, 8(2)*, 147-149.
Kirkegaard, E. (ed). (2010). *European Eel and Aquaculture*. DTU Aqua Report No 229-2010. Retrieved from http://www.aqua.dtu.dk/~/media/Institutter/Aqua/Publikationer/Forskningsrapporter_201_250/229_2010_european_eel_and_aquaculture.ashx

Kim, W.S., Ok, H.N., Kim, D.H., Kim, H.Y., & Oh, M.J. (2011). Current status of pathogen infection in cultured eel Anguilla japonica between 2000 and 2010. *J. Fish Pathol. 24 (3)*, 237–245.

Kou, G.H. & Lo, C.F. (1994). Early development of Pleistophora anguillarum in an eel cell line and in elvers (Anguilla japonica). In AFS, (Eds). *Proceedings of the International Symposium on Aquatic Animal Health*, Seattle, Washington (USA), 4-8 September 1994. Bethesda, USA., American Fisheries Society

Lee, N. S., Nomura, Y., & Miyazaki, T. (1999). Gill lamellar pillar cell necrosis, a new birnavirus disease in Japanese eels. *Diseases of aquatic organisms, 37*, 13-21.

Liao, I.C. (1998). Toward a sustainable aquaculture development. In Hotta, M. (ed.), *Improving Management of Aquaculture in Asia* (62-77). Japan: Asian Productivity Organization.

Liao, I.C. (2005). Aquaculture practices in Taiwan and its visions. *Journal of the Fisheries Society of Taiwan, 32*(3), 193-206.

Liao, I.C. & Chao, N-H. (2007). Taiwanese aquaculture at the crossroads. In P. Leung, C-S. Lee, & P.J. O'Bryen (Eds.), *Species & System Selection for Sustainable Aquaculture* (161-175). Iowa: Blackwell Publishing.

Luo, G., Zhu, Z. & Bao, C. 2009. Analysis of Chinese Aquaculture Scheming. *Environmental Pollution and Control*, 31 (2): 87–89.

Ma, Zhijun, et al. "Are artificial wetlands good alternatives to natural wetlands for waterbirds?–A case study on Chongming Island, China." *Biodiversity & Conservation* 13.2 (2004): 333-350.

Ma, Yan-ju, Bo SU, and Zhen-jin MENG. "Autumn and Winter Survey of Waterbirds in National Natural Reserve of Beilun Estuary of Guangxi." *Guangxi Sciences* 1 (2011): 024.

Miyai, T., Aoyama, J., Sasai S, Inoue, J., Miller, MJ. & Tsukamoto, K. (2004) Ecological aspects of the downstream migration of introduced European eels in the Uono River, Japan. *Env Biol Fish 71*, 105–114

Miao, W. W., & Jiang, M. (2007). Environmental impact and sustainable development of aquaculture in China. *Journal of Agro-Environment Science*, *26*, 319-323.

Miller, M.J., and J.M. Casselman. 2014 (in press). The American eel: A fish of mystery and sustenance for humans. *In* K. Tsukamoto and M. Kuroki (eds.), Eels and Humans, Humanity and the Sea, 155. DOI 10.1007/978-4-431-54529-3_11, © Springer Japan 2014.

Ming, L., 2006. Study on establishing a perfect food safety system in China. *Management, 11* (1), 111–119.

Ministry of Environment Korea. *Standards for Water Quality Environment.* Retrieved from http://eng.me.go.kr/content.do?method=moveContent&menuCode=pol_wat&categoryCode=02

Ministry of the Environment Government of Japan. Water Pollution Control Law, Law number 138 of 1970, http://www.env.go.jp/en/laws/water/wlaw/index.html.

Minegishi, Y. Henkel, C.V., Dirks, R.P., & van den Thillart, G.E.E.J.M. (2012). Genomics in eels – towards aquaculture in biology. *Marine Biotechnology, 14*, 583-590.

Molnár, K., Székely, C., & Baska, F. (1991). Mass mortality of eel in Lake Balaton due to Anguillicola crassus infection. *Bulletin of the European Association of Fish Pathologists, 11(6)*, 211-212.

Mori, R., Nabeshima, K., & Yamada, N, (2013). Food safety control system of Chinese eel exports and its challenges. *Institute of Developing Economies discussion paper 418*. Retrieved from http://www.ide.go.jp/English/Publish/Download/Dp/pdf/418.pdf

Münderle, M., Taraschewski, H., Klar, B., Chang, C. W., Shiao, J. C., Shen, K. N., ... & Tzeng, W. N. (2006). Occurrence of *Anguillicola crassus* (*Nematoda: Dracunculoidea*) in Japanese eels *Anguilla japonica* from a river and an aquaculture unit in SW Taiwan. *Diseases of aquatic organisms*, *71*(2), 101-108.

Nielsen, T., & Prouzet, P. (2008). Capture-based aquaculture of the wild European eel (*Anguilla anguilla*). In Lovatelli, A., & Holthus, P.F. (eds). *Capture-based Aquaculture - Global Overview.* (141-168). FAO Fisheries Technical Paper, 508.

Ogawa, K., & Egusa, S. (1980). Gyrodactylus infestations of cultured eels (*Anguilla japonica* and *A. anguilla*) in Japan. *Fish Pathology, 15(2)*, 95-99.

Okamura, A., Zhang, H., Mikawa, N., Kotake, A., Yamada, Y., Utoh, T., … Tsukamoto, K. (2007). Decline in non-native freshwater eels in Japan: ecology and future perspectives. *Environmental Biology of Fishes*, *81*(3), 347–358. doi:10.1007/s10641- 007-9205-x

Ottolenghi, F., Silvestri, C., Giordano, P., Lovatelli, A., New, M.B. (2004). *Capture-based aquaculture: The fattening of eels, groupers, tunas and yellowtails*. Rome, Italy: Food and Agriculture Organization.

Price, Iola M., and John G. Nickum. "Aquaculture and birds: the context for controversy." *Colonial Waterbirds* (1995): 33-45.

Quanzhang, L., & Xinling, Z. (1994). Studies on the pathogenic bacteria of the lover-kidney disease of eels (*Anguiilla japonica*). *Acta Hydrobiologica Sinica, 4*.

Ringuet, S., Muto, F. and Raymakers, C. (2002). Eels: their Harvest and Trade in Europe and Asia. *TRAFFIC Bulletin 19*(2): 80–106.

Shih, H. H., Lu, C.C. & Chen, S.N. (1993). Eel herpesvirus in Formosa: *A herpesvirus* from cultured Japanese eel. *Coastal Fisheries Series, 40*, 86-96.

Tacon, A. G., & Metian, M. (2008). Global overview on the use of fish meal and fish oil in industrially compounded aquafeeds: Trends and future prospects. *Aquaculture*, *285*(1), 146-158.

Takeda, I. (2010). The Measures for Sustainable Marine Aquaculture in Japan. *Aquaculture*, *100*(1,215), 434.

Tam, W., Yang, D., 2005. Food safety and development of regulatory institutes in China. *Asian Perspectives, 29*(4), 5–36.

Tanaka, H., Kagawa, H., Ohta, H., Unuma, T., & Nomura, K. (2003). The first production of glass eel in captivity: fish reproductive physiology facilitates great progress in aquaculture. *Fish Physiology and Biochemistry, 28*, 493-497.

Taiwan Review. (2009). The Future of Aquaculture. Retrieved from http://taiwanreview.nat.gov.tw/fp.asp?xItem=52871&CtNode=128

Tucker, C.S., Hargreaves, J.A., & Boyd, C.E. (2008). Better management practices for freshwater pond aquaculture. In Tucker, A., & Hargreaves, J.A. (Eds.), *Environmental Best Management Practices for Aquaculture* (151-226). Iowa: Blackwell Publishing.

United States Department of Agriculture (USDA). *Global Agricultural Trade System (GATS) Online*. Available from http://www.fas.usda.gov/gats/default.aspx

Usui, A. 1974. Eel Culture. Fishing News Books. Blackwell Scientific Publications Ltd.: London.

Venugopal, V. (Ed.). (2005). *Seafood Processing: Adding Value Through Quick Freezing, Retortable Packaging and Cook-Chilling*. CRC Press.

Wang, Y., Zhang, X.H. and Austin, B. (2010). Comparative analysis of the phenotypic characteristics of high- and low virulent strains of *Edwardsiella tarda*. *J Fish Dis 33*, 985–994.

Weimin, M. & Mengqing, L. (2007). Analysis of feeds and fertilizers for sustainable aquaculture development in China. In Hasan, M.R., Hecht, T., De Silva, S.S. & Tacon, A.G.J. (eds). *Study and analysis of feeds and fertilizers for sustainable aquaculture Development* (141-190). Fisheries and Aquaculture Organization (FAO) Fisheries Technical Paper, 497.

Wu, J.T. (1999). Ted Case Studies – Eel Farming in Taiwan. Retrieved from http://www1.american.edu/TED/eelfarm.htm

Yokoyama, H. (2003). Environmental quality criteria for fish farms in Japan. *Aquaculture*, *226*(1- 4), 45–56. doi:10.1016/S0044-8486(03)00466-6

Yoo, H.S., Kwon, B.J., Yoon, Y.D., Park, J.M., & Choi, S.H. (1990). Characteristics of *Aeromonas hydrophila* isolated from fresh water fishes in Korea. *Res. Rep. RDA 32 (1),* 63–73.

Yu-Tzu, C. (2003, November 13). Eel exports to Japan suspended. *Taipei Times*. Retrieved from http://www.taipeitimes.com/News/taiwan/archives/2003/11/13/ 2003075644

Zeng, Y., Ma, Y., Wei, C., Jiao, N., Tang, K., Wu, Z., & Jian, J. (2010). Bacterial diversity in various coastal mariculture ponds in Southeast China and in diseased eels as revealed by culture and culture-independent molecular techniques. *Aquaculture Research, 41(9)*, e172-e186.

Zhang, X. (2007). Aquaculture in China. In P. Leung, C-S. Lee, & P.J. O'Bryen (Eds.), *Species & System Selection for Sustainable Aquaculture* (131-144). Iowa: Blackwell Publishing.

Appendix 1 - Data points and all scoring calculations

This is a condensed version of the criteria and scoring sheet to provide access to all data points and calculations. See the Seafood Watch Aquaculture Criteria document for a full explanation of the criteria, calculations and scores. Yellow cells represent data entry points.

Criterion 1: Data quality and availability

Data Category	Relevance (Y/N)	Data Quality	Score (0-10)
Industry or production statistics	*Yes*	5	5
Effluent	Yes	2.5	2.5
Locations/habitats	Yes	2.5	2.5
Predators and wildlife	Yes	0	0
Chemical use	Yes	2.5	2.5
Feed	Yes	5	5
Escapes, animal movements	Yes	2.5	2.5
Disease	Yes	2.5	2.5
Source of stock	Yes	5	5
Other – (e.g. GHG emissions)	No	Not Relevant	N/A
Total			**27.5**

C1 Data Final Score	3.05	RED

Criterion 2: Effluents

Factor 2.1a - Biological waste production score

Protein content of feed (%)	48
eFCR	1.4
Fertilizer N input (kg N/ton fish)	0
Protein content of harvested fish (%)	14.5
N content factor (fixed)	*0.16*
N input per ton of fish produced (kg)	107.52
N in each ton of fish harvested (kg)	23.2
Waste N produced per ton of fish (kg)	**84.32**

Factor 2.1b - Production System discharge score

Basic production system score	0.75
Adjustment 1 (if applicable)	0
Adjustment 2 (if applicable)	0
Adjustment 3 (if applicable)	0
Discharge (Factor 2.1b) score	**0.75**

80% of the waste produced by the fish is discharged from the farm

2.2 – Management of farm level and cumulative impacts and appropriateness to the scale of the industry

China

Factor 2.2a - Regulatory or management effectiveness

Question	Scoring	Score
1 - Are effluent regulations or control measures present that are designed for, or are applicable to aquaculture?	Yes	1
2 - Are the control measures applied according to site-specific conditions and/or do they lead to site-specific effluent, biomass or other discharge limits?	Moderately	0.5
3 - Do the control measures address or relate to the cumulative impacts of multiple farms?	Partly	0.25
4 - Are the limits considered scientifically robust and set according to the ecological status of the receiving water body?	Moderately	0.5
5 - Do the control measures cover or prescribe including peak biomass, harvest, sludge disposal, cleaning etc?	No	0
		2.25

Factor 2.2b - Enforcement level of effluent regulations or management

Question	Scoring	Score
1 - Are the enforcement organizations and/or resources identifiable and contactable, and appropriate to the scale of the industry?	Moderately	0.5
2 - Does monitoring data or other available information demonstrate active enforcement of the control measures?	Moderately	0.5
3 - Does enforcement cover the entire production cycle (i.e. are peak discharges such as peak biomass, harvest, sludge disposal, cleaning included)?	Moderately	0.5
4 - Does enforcement demonstrably result in compliance with set limits?	Partly	0.25
5 - Is there evidence of robust penalties for infringements?	no	0
		1.75

F2.2 Score (2.2a*2.2b/2.5)	**1.575**

C2 Effluent Final Score	**2.00**	**RED**
	Critical?	NO

Japan

Factor 2.2a - Regulatory or management effectiveness

Question	Scoring	Score
1 - Are effluent regulations or control measures present that are designed for, or are applicable to aquaculture?	Yes	1

2 - Are the control measures applied according to site-specific conditions and/or do they lead to site-specific effluent, biomass or other discharge limits?	Moderately	0.5
3 - Do the control measures address or relate to the cumulative impacts of multiple farms?	Yes	1
4 - Are the limits considered scientifically robust and set according to the ecological status of the receiving water body?	Moderately	0.5
5 - Do the control measures cover or prescribe including peak biomass, harvest, sludge disposal, cleaning etc?	No	0
		3

Factor 2.2b - Enforcement level of effluent regulations or management

Question	Scoring	Score
1 - Are the enforcement organizations and/or resources identifiable and contactable, and appropriate to the scale of the industry?	Moderately	0.5
2 - Does monitoring data or other available information demonstrate active enforcement of the control measures?	Partly	0.25
3 - Does enforcement cover the entire production cycle (i.e. are peak discharges such as peak biomass, harvest, sludge disposal, cleaning included)?	Partly	0.25
4 - Does enforcement demonstrably result in compliance with set limits?	No	0
5 - Is there evidence of robust penalties for infringements?	Partly	0
		1.25

F2.2 Score (2.2a*2.2b/2.5)	**1.5**

C2 Effluent Final Score	**2.00**	**RED**
	Critical?	NO

Taiwan

Factor 2.2a - Regulatory or management effectiveness

Question	Scoring	Score
1 - Are effluent regulations or control measures present that are designed for, or are applicable to aquaculture?	Yes	1
2 - Are the control measures applied according to site-specific conditions and/or do they lead to site-specific effluent, biomass or other discharge limits?	Moderately	0.5
3 - Do the control measures address or relate to the cumulative impacts of multiple farms?	Mostly	0.75
4 - Are the limits considered scientifically robust and set according to the ecological status of the receiving water body?	Moderately	0.5
5 - Do the control measures cover or prescribe including peak biomass, harvest, sludge disposal, cleaning etc?	Moderately	0.5
		3.25

Factor 2.2b - Enforcement level of effluent regulations or managen

Question	Scoring	Score
1 - Are the enforcement organizations and/or resources identifiable and contactable, and appropriate to the scale of the industry?	Moderately	0.5
2 - Does monitoring data or other available information demonstrate active enforcement of the control measures?	Partly	0.25
3 - Does enforcement cover the entire production cycle (i.e. are peak discharges such as peak biomass, harvest, sludge disposal, cleaning included)?	N0	0
4 - Does enforcement demonstrably result in compliance with set limits?	No	0
5 - Is there evidence of robust penalties for infringements?	Mostly	0.75
		1.5

F2.2 Score (2.2a*2.2b/2.5)	**1.95**

C2 Effluent Final Score	**2.00**	**RED**
	Critical?	NO

South Korea

Factor 2.2a - Regulatory or management effectiveness

Question	Scoring	Score
1 - Are effluent regulations or control measures present that are designed for, or are applicable to aquaculture?	Yes	1
2 - Are the control measures applied according to site-specific conditions and/or do they lead to site-specific effluent, biomass or other discharge limits?	Mostly	0.75
3 - Do the control measures address or relate to the cumulative impacts of multiple farms?	Yes	1
4 - Are the limits considered scientifically robust and set according to the ecological status of the receiving water body?	Yes	1
5 - Do the control measures cover or prescribe including peak biomass, harvest, sludge disposal, cleaning etc?	Partly	0.25
		4

Factor 2.2b - Enforcement level of effluent regulations or manager

Question	Scoring	Score
1 - Are the enforcement organizations and/or resources identifiable and contactable, and appropriate to the scale of the industry?	Mostly	0.75
2 - Does monitoring data or other available information demonstrate active enforcement of the control measures?	No	0
3 - Does enforcement cover the entire production cycle (i.e. are peak discharges such as peak biomass, harvest, sludge disposal, cleaning included)?	No	0

4 - Does enforcement demonstrably result in compliance with set limits?	No	0
5 - Is there evidence of robust penalties for infringements?	No	0
		0.75

F2.2 Score (2.2a*2.2b/2.5)	**1.2**

C2 Effluent Final Score	**2.00**	**RED**
	Critical?	NO

Criterion 3: Habitat

3.1 Habitat conversion and function

F3.1 Score	**6.00**

3.2 Habitat and farm siting management effectiveness (appropriate to the scale of the industry)

China

Factor 3.2a – Regulatory or management effectiveness

Question	Scoring	Score
1 - Is the farm location, siting and/or licensing process based on ecological principles, including an EIAs requirement for new sites?	Yes	1
2 - Is the industry's total size and concentration based on its cumulative impacts and the maintenance of ecosystem function?	Moderately	0.5
3 – Is the industry's ongoing and future expansion appropriate locations, and thereby preventing the future loss of ecosystem services?	Partly	0.25
4 - Are high-value habitats being avoided for aquaculture siting? (i.e. avoidance of areas critical to vulnerable wild populations; effective zoning, or compliance with international agreements such as the Ramsar treaty)	yes	1
5 - Do control measures include requirements for the restoration of important or critical habitats or ecosystem services?	no	0
		2.75

Factor 3.2b – Siting regulatory or management enforcement

Question	Scoring	Score
1 - Are enforcement organizations or individuals identifiable and contactable, and are they appropriate to the scale of the industry?	Moderately	0.5
2 - Does the farm siting or permitting process function according to the zoning or other ecosystem-based management plans articulated in the control measures?	Moderately	0.5
3 - Does the farm siting or permitting process take account of other farms and their cumulative impacts?	Partly	0.25
4 - Is the enforcement process transparent - e.g. public availability of farm locations and sizes, EIA reports, zoning plans, etc?	no	0
5 - Is there evidence that the restrictions or limits defined in the control measures are being achieved?	no	0
		1.375

F3.2 Score (2.2a*2.2b/2.5)	1.38

C3 Habitat Final Score	4.46	YELLOW
	Critical?	NO

Japan

Factor 3.2a – Regulatory or management effectiveness

Question	Scoring	Score
1 - Is the farm location, siting and/or licensing process based on ecological principles, including an EIAs requirement for new sites?	Moderately	0.5
2 - Is the industry's total size and concentration based on its cumulative impacts and the maintenance of ecosystem function?	Moderately	0.5
3 – Is the industry's ongoing and future expansion appropriate locations, and thereby preventing the future loss of ecosystem services?	Moderately	0.5
4 - Are high-value habitats being avoided for aquaculture siting? (i.e. avoidance of areas critical to vulnerable wild populations; effective zoning, or compliance with international agreements such as the Ramsar treaty)	Yes	1
5 - Do control measures include requirements for the restoration of important or critical habitats or ecosystem services?	Yes	1
		3.5

Factor 3.2b – Siting regulatory or management enforcement

Question	Scoring	Score
1 - Are enforcement organizations or individuals identifiable and contactable, and are they appropriate to the scale of the industry?	Moderately	0.5
2 - Does the farm siting or permitting process function according to the zoning or other ecosystem-based management plans articulated in the control measures?	Mostly	0.75
3 - Does the farm siting or permitting process take account of other farms and their cumulative impacts?	Partly	0.25
4 - Is the enforcement process transparent - e.g. public availability of farm locations and sizes, EIA reports, zoning plans, etc?	No	0
5 - Is there evidence that the restrictions or limits defined in the control measures are being achieved?	No	0
		1.5

F3.2 Score (2.2a*2.2b/2.5)	2.10

C3 Habitat Final Score	4.70	YELLOW
	Critical?	NO

Taiwan

Factor 3.2a – Regulatory or management effectiveness

Question	Scoring	Score

1 - Is the farm location, siting and/or licensing process based on ecological principles, including an EIAs requirement for new sites?	Mostly	0.75
2 - Is the industry's total size and concentration based on its cumulative impacts and the maintenance of ecosystem function?	no	0
3 – Is the industry's ongoing and future expansion appropriate locations, and thereby preventing the future loss of ecosystem services?	No	0
4 - Are high-value habitats being avoided for aquaculture siting? (i.e. avoidance of areas critical to vulnerable wild populations; effective zoning, or compliance with international agreements such as the Ramsar treaty)	yes	1
5 - Do control measures include requirements for the restoration of important or critical habitats or ecosystem services?	no	0
		1.75

Factor 3.2b – Siting regulatory or management enforcement

Question	Scoring	Score
1 - Are enforcement organizations or individuals identifiable and contactable, and are they appropriate to the scale of the industry?	Moderately	0.5
2 - Does the farm siting or permitting process function according to the zoning or other ecosystem-based management plans articulated in the control measures?	Partly	0.25
3 - Does the farm siting or permitting process take account of other farms and their cumulative impacts?	No	0
4 - Is the enforcement process transparent - e.g. public availability of farm locations and sizes, EIA reports, zoning plans, etc?	Partly	0.25
5 - Is there evidence that the restrictions or limits defined in the control measures are being achieved?	Partly	0.25
		1.25

F3.2 Score (2.2a*2.2b/2.5)	**0.875**

C3 Habitat Final Score	**4.29**	**YELLOW**
	Critical?	NO

<u>South Korea</u>

Factor 3.2a – Regulatory or management effectiveness

Question	Scoring	Score
1 - Is the farm location, siting and/or licensing process based on ecological principles, including an EIAs requirement for new sites?	yes	1
2 - Is the industry's total size and concentration based on its cumulative impacts and the maintenance of ecosystem function?	No	0
3 – Is the industry's ongoing and future expansion appropriate locations, and thereby preventing the future loss of ecosystem services?	No	0
4 - Are high-value habitats being avoided for aquaculture siting? (i.e. avoidance of areas critical to vulnerable wild populations; effective zoning, or compliance with international agreements such as the Ramsar treaty)	yes	1
5 - Do control measures include requirements for the restoration of important or critical habitats or ecosystem services?	Yes	1
		3

Factor 3.2b – Siting regulatory or management enforcement

Question	Scoring	Score
1 - Are enforcement organizations or individuals identifiable and contactable, and are they appropriate to the scale of the industry?	Moderately	0.5
2 - Does the farm siting or permitting process function according to the zoning or other ecosystem-based management plans articulated in the control measures?	Moderately	0.5
3 - Does the farm siting or permitting process take account of other farms and their cumulative impacts?	No	0
4 - Is the enforcement process transparent - e.g. public availability of farm locations and sizes, EIA reports, zoning plans, etc?	No	0
5 - Is there evidence that the restrictions or limits defined in the control measures are being achieved?	No	0
		1

F3.2 Score (2.2a*2.2b/2.5)	**1.20**

C3 Habitat Final Score	**4.40**	**YELLOW**
	Critical?	NO

Criterion 4: Evidence of Risk of Chemical Use

China and Taiwan

Chemical Use parameters	Score	
C4 Chemical Use Score	**0.00**	
C4 Chemical Use Final Score	**0.00**	**RED**
Critical?	NO	

South Korea and Japan

Chemical Use parameters	Score	
C4 Chemical Use Score	**4.00**	
C4 Chemical Use Final Score	**4.00**	**YELLOW**
Critical?	NO	

Criterion 5: Feed

5.1 Wild Fish Use

Factor 5.1a – Fish In: Fish Out (FIFO)

Fishmeal inclusion level (%)	58.5
Fishmeal from byproducts (%)	84

% FM	9.36
Fish oil inclusion level (%)	4
Fish oil from byproducts (%)	0
% FO	4
Fishmeal yield (%)	22.5
Fish oil yield (%)	5
eFCR	1.4
FIFO fishmeal	0.58
FIFO fish oil	1.12
Greater of the 2 FIFO scores	1.12
FIFO Score	**7.20**

Factor 5.1b – Sustainability of the Source of Wild Fish (SSWF)

SSWF	-6
SSWF Factor	-0.672

F5.1 Wild Fish Use Score	**6.53**

5.2 Net Protein Gain or Loss

Protein INPUTS		
Protein content of feed		48
eFCR		1.4
Feed protein from NON-EDIBLE sources (%)		67
Feed protein from EDIBLE CROP soruces (%)		33
Protein OUTPUTS		
Protein content of whole harvested fish (%)		15.5
Edible yield of harvested fish (%)		68.5
Non-edible byproducts from harvested fish used for other food production		0
Protein IN		15.83
Protein OUT		10.6175
Net protein gain or loss (%)		-32.9435
	Critical?	NO
F5.2 Net protein Score	**6.00**	

5.3 Feed Footprint

Factor 5.3a – Ocean area of primary productivity appropriated by feed ingredients per ton of farmed seafood

Inclusion level of aquatic feed ingredients (%)	62.5
eFCR	1.4
Average Primary Productivity (C) required for aquatic feed ingredients (ton C/ton fish)	*69.7*

Average ocean productivity for continental shelf areas (ton C/ha)	*2.68*
Ocean area appropriated (ha/ton fish)	22.76

Factor 5.3b – Land area appropriated by feed ingredients per ton of production

Inclusion level of crop feed ingredients (%)	37.5
Inclusion level of land animal products (%)	0
Conversion ratio of crop ingedients to land animal products	*2.88*
eFCR	1.4
Average yield of major feed ingredient crops (t/ha)	*2.64*
Land area appropriated (ha per ton of fish)	0.20

Value (Ocean + Land Area)	**22.96**

F5.3 Feed Footprint Score	**2.00**

C5 Feed Final Score	**5.26**	**YELLOW**
	Critical?	**NO**

Criterion 6: Escapes

Factor 6.1a – Escape Risk

Escape Risk	**2**

Recapture & Mortality Score (RMS)	
Estimated % recapture rate or direct mortality at the escape site	0
Recapture & Mortality Score	0
Factor 6.1a Escape Risk Score	**2**

Factor 6.1b – Invasiveness

Part B – Non-Native Species

Score	1.5

Part C – Native and non-native species

Question	**Score**	
Do escapees compete with wild native populations for food or habitat?	yes	1
Do escapees act as additional predation pressure on wild native populations?	yes	1
Do escapees compete with wild native populations for breeding partners or disturb breeding behavior of the same or other species?	To some Extent	0.5
Do escapees modify habitats to the detriment of other species (e.g. by feeding, foraging, settlement or other)?	No	0
Do escapees have some other impact on other native species or habitats?	No	0
	2.5	2.5

F 6.1b Score		4.0

Final C6 Score	3.00	RED
	Critical?	NO

Criterion 7: Diseases

Pathogen and parasite parameters	Score	
C7 Biosecurity	2.00	
C7 Disease; pathogen and parasite Final Score	**2.00**	
Critical?	NO	**RED**

Criterion 8: Source of Stock

Source of stock parameters	Score	
C8 % of production from hatchery-raised broodstock or natural (passive) settlement	0	
C8 Source of stock Final Score	**0**	
		RED

Exceptional Factor 9X: Wildlife and predator mortalities

Wildlife and predator mortality parameters	Score	
F3.3X Wildlife and Predator Final Score	**-6.00**	**YELLOW**
Critical?	NO	

Exceptional Factor 10X: Escape of unintentionally introduced species

Escape of unintentionally introduced species parameters	Score	
F6.2Xa International or trans-waterbody live animal shipments (%)	0.00	
F6.2Xb Biosecurity of source/destination	10.00	
F6.2X Escape of unintentionally introduced species Final Score	**-8.00**	
		RED

Appendix 2 – Interim Update (2021)

An Interim Update of this assessment was conducted in July 2021 in the most-up-to-date Seafood Watch Aquaculture Standard Version 4.0. Interim Updates focus on an assessment's limiting (i.e., Critical or Red) criteria (inclusive of a review of the availability and quality of data relevant to those criteria), so this review evaluates the Source of Stock criterion. No information was found or received that would suggest the final rating is no longer accurate. No edits were made to the text of the report (except an update note in the Executive Summary, Introduction, and all updated criteria). The following text summarizes the findings of the review.

Interim Update Scoring Summary

Results of the interim update support the findings of the previous assessment and the Overall Recommendation for eel (*Anguilla anguilla, A. japonica, A. rostrata*) grown in ponds and managed indoor facilities that use some degree of water recycling in East Asia (largely China, Japan, South Korea and Taiwan) remains Avoid with a Red rating. The recommendation and rating are driven by one Critical criterion assessed in the interim update, Criterion 8X – Source of Stock. According to the Seafood Watch standard, one Critical criteria automatically results in a Red rating and an Avoid recommendation.

Executive Summary (2021 Update)

Cultured production of freshwater eel has increased steadily over the last three decades to the extent that 97% of global production is now farmed. The vast majority of eel farming (98%) takes place in four East Asian nations: China, Japan, South Korea and Taiwan. Historically, Japan has traditionally been the primary producer, and consumer, of cultured eels but when China scaled-up its production in the 1990s it immediately moved to the fore and has remained the dominant producer ever since. The latest available data from the Food and Agriculture Organization of the United Nations (FAO) indicate that 265,759 metric tonnes (MT) of farmed eel was produced in East Asia in 2019, of which 88% was cultured in China. Almost all of the eel products imported into the US from East Asia come from China and annual imports are in the region of 5 - 6,000 MT.

Although a great deal of funding and research has been focused on closing the eel lifecycle, multiple bottlenecks to achieving commercial hatchery success are yet to be overcome; as a result, modern eel farms continue to be 100% reliant on wild-caught juveniles. Although described as freshwater eels, the European, Japanese and American eel all begin and end their lives in the marine environment. Much of the eel lifecycle still remains unknown to science and a natural spawning event has yet to be observed. Each of these species are considered to belong to one single spawning stock: partially overlapping one another, the spawning areas of the European and American eel are believed to be in the Sargasso Sea, near the island of Bermuda, whereas the spawning grounds of the Japanese eel are believed to be located in the

North Equatorial Current, west of the Mariana Islands. After a spawning event occurs, eel larvae drift for months to years on ocean currents, until they reach their respective continental ranges and metamorphose into glass eels. At this developmental stage they are suitable for on-growing in captivity, thus this is the life stage at which they are targeted by glass eel fishers and sold to eel farms in East Asia. With regard to the Seafood Watch Aquaculture Standard, this factor has significant ramifications in terms of the environmental impacts that are attributable to the eel farming sector, especially since a sharp decline in the abundance of northern temperate species has been observed in recent decades. This is particularly evident in the European stock, the recruitment of which has declined by around 90%.

This report is a reappraisal of an assessment that was originally completed in 2014. At that time, based on the resources and data that were available, the Source of Stock Criterion was originally ranked red, due to the sector's total reliance on wild juveniles. In the interim, however, much has changed across the global glass eel procurement landscape and East Asian eel production has become inextricably entwined with issues pertaining to wildlife trafficking and IUU fisheries. Global eel supply chains lack a coherent traceability system; as a result, cultured eel products from East Asia are incontrovertibly tainted with inputs of illegally sourced juveniles. Since illegal and legal glass eels are shipped to East Asia together, they are therefore also stocked and harvested together. Subsequently, these comingled legal and illegal eel products are purchased by, and shipped to, international seafood buyers around the world, and there is no simple way for consumers to ascertain if the eel they have purchased is legal or not. The volume of illegal Japanese and American eel being traded internationally is challenging to accurately determine but for the European eel, which is afforded greater protection both by the EU Eel Regulation and its CITES-listing, it was recently estimated that one quarter of the entire annual recruitment of incoming wild juveniles was being illegally harvested upon arrival in European waters and subsequently trafficked into East Asia for farming purposes.

Guided by this new information, the analytical process for this update has therefore focused foremost on unpacking data on the global eel value chain and the current conservation status of the eel species involved. This analysis resulted in a Critical determination being assessed for this Criterion 8X. Determination of this Critical score obviated the need to re-assess all other criteria, thus these remain as written in 2014: these criteria pertain to impacts associated with effluent, habitat, wildlife and predator interactions, chemical use, feed production, escapes, introduction of non-native organisms (other than the farmed species), and disease. In addition to a thorough re-evaluation of Criterion 8X, the introduction to this update has also been revised accordingly to reflect the current status of the East Asian eel farming sector.

Introduction (2021 Update)

Scope of the analysis and ensuing recommendation

Species
European Eel (*Anguilla anguilla*)
Japanese Eel (*Anguilla japonica*)
American Eel (*Anguilla rostrata*)

Geographic Coverage
East Asia: China, Japan, South Korea and Taiwan

Production Method(s)
Ponds and managed indoor facilities that use some degree of water recycling

Eels: A global species overview
Eels, which belong to the order Anguilliformes, are represented globally by over 800 species (Miller 2009). These can be further classified into 15 different eel families, one of which is the *Anguillidae*, also known as the freshwater eels. The *Anguillidae* are facultative catadromous, ray-finned fish that live in estuarine and freshwater habitats as juveniles but later, as adults, migrate to the ocean to spawn (Jacoby et al. 2015; Shiraishi & Crook 2015; Miller 2009). While it is assumed that eels die after reproduction, this theory has yet to be supported by direct observation (Tsukamoto & Kuroki 2014; USFWS 2015a). The genus, *Anguilla*, contains 19 different species and subspecies (Tsukamoto et al. 2020), including *Anguilla anguilla* (European eel), *Anguilla japonica* (Japanese eel), and *Anguilla rostrata* (American eel). Both globally and in the US, these three species are of particular commercial significance, thus these species comprise the primary focus of this report.

Eels first appeared on Earth tens of millions of years ago and, through the ages, they have become entwined in the cultural and culinary traditions of the many regions across their range. Until a few decades ago, they were reportedly abundant and widespread; often referenced as one of the most commonly caught freshwater fish, eels were particularly popular as they were robust and easily transported alive (Tsukamoto & Kuroki 2014). In 19th Century Europe, eels reportedly accounted for one third of the value of freshwater fisheries landings (WWF 2021). Eel abundance, however, has drastically diminished, and experts advise that the recruitment of temperate species is now less than 10% of what it once was (Jellyman 2021; Dekker 2003). The IUCN Red List presently ranks both the Japanese and American eel as endangered and the European eel as critically endangered, further noting that all three species exhibit a decreasing population trend (Pike et al. 2020a; Pike et al. 2020b; Jacoby et al. 2017). Additionally, the IUCN

Anguillid Eel Specialist Group (AESG) notes that concerns for all members of the family *Anguillidae* have been mounting over the last 30 years, due to their declining numbers[16].

The complex lifecycle of eels: the known and the unknown

Although freshwater eels have been the subject of numerous scientific studies, certain aspects of their complex lifecycle and ecology still remain unknown. For centuries, one of the biggest mysteries that scientists sought to resolve was where and how eels reproduce, since mating had never been observed and neither their eggs nor larvae had been identified: the Greek philosopher, Aristotle, through experimentation, concluded that eels were spontaneously generated out of mud (Dekker & Beaulaton 2016b), whereas Pliny believed that they rubbed themselves on rocks and that the sloughed off skin subsequently grew into new eels; others believed they grew from horses' hair that had fallen in water (Jarvis 2020; Orth 2016; McCartney 1920). As time went on, and the conundrum of where and how eels reproduce persisted, this state of affairs gave rise to much discussion and common usage of the term, the 'Eel Problem' (Dekker & Beaulaton 2016a).

Figure 1: Leptocephali of the Japanese eel (*Anguilla japonica*) which were artificially spawned and reared at the Japanese IRAGO Institute - note that these larvae are around 200 days old and 30-50 mm long - Photo Credit: Yoshiaki Yamada (Miller 2009)

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[16] https://www.zsl.org/conservation/species/fish-and-invertebrates/eel-conservation/iucn-anguillid-eel-specialist-group

A significant breakthrough occurred in 1892 - 1893, when Italian physician and zoologist, Giovanni Battista Grassi, along with his pupil and assistant, Salvatore Calandruccio, identified the leptocephalus (larval) stage of the European eel, as a result of witnessing it metamorphosize into a glass eel, which is the next stage of development (van Ginneken & Maes 2005; Pampiglione & Giannetto 2001). Both marine and freshwater eels, plus other members of the superorder Elopomorpha, such as tarpon and ladyfish, start out as leptocephali; these teleostean larvae resemble flat, transparent leaves and, since they bear no resemblance to their adult form, had hitherto been considered to be a unique and unrelated species of marine fish (Miller 2009). Identifying fish from their larval form is often challenging for ichthyologists due to the significant changes that occur during early developmental stages[17]. Grassi and Calandruccio also theorized that the freshwater European eel most likely spawned in the Mediterranean Sea in deep water (Tesch & Thorpe 2003a; Boëtius & Harding 1985).

A number of years later, in 1912, Danish biologist and oceanographer, Johannes Schmidt, published his findings that the spawning place of *A. anguilla* must be in the Atlantic, not in the Mediterranean as previously proposed and that the Sargasso Sea could perhaps be a principle spawning region (Schmidt 1912). It was not until 1922, however, that he felt he had enough evidence to publish a definitive paper on the topic, in which he surmised that reproduction of both *A. anguilla and A. rostrata* only occurred in this region. He reached this hypothesis over the course of multiple ocean expeditions, during which he collected anguillid leptocephali from all over the northern Atlantic Ocean, observing that the smallest specimens of newly hatched larvae were only found in the southern Sargasso Sea (Tesch & Thorpe 2003a; Boëtius & Harding 1985). These investigations proved that anguillid eels travel thousands of kilometers to their offshore spawning grounds, as do anguillid leptocephali, when they return on the ocean currents to the recruitment areas along the continental shelf, a process estimated to last around two years on average for *A. anguilla* (Pike et al. 2020a; Musing et al. 2018), up to a year for *A. rostrata* (GoC 2016), and 5 - 6 months for *A. japonica* (Pike et al. 2020b). It was not until several decades later that the spawning grounds of the Japanese eel were also tentatively identified; these are likely located in the North Equatorial Current, west of the Mariana Islands (Hamidoghli et al. 2019; Tsukamoto 1992). To date, despite these scientific discoveries, researchers are yet to observe or document a wild eel spawning event (Dekker & Beaulaton 2016b). In fact, the mere presence of sexually mature anguillid eels in the open ocean was only confirmed for the first time in 2005, when Japanese scientists, using a large, mid-water trawl net, were successful in capturing a number of adult Japanese eels in close proximity to the likely spawning grounds identified for this species (Chow et al. 2008).

Soon after, in 2006, a multinational team of scientists used miniaturized pop-up satellite archival transmitters (PSATs) to tag a number of European eels during their ~5,000 km spawning migration; they were successful in tracking ~1,300 km of the journey before the tags ‘popped up’ to the ocean surface and relayed their data via satellite (Aarestrup et al. 2009). Similarly, in 2014, Canadian researchers used PSAT technology to track a number of American eels, one of which was successfully tracked to the northern limit of their spawning grounds in

[17] https://www.sciencenews.org/article/underwater-photos-deep-sea-fish-larvae-capture-new-views-detail

the Sargasso Sea, a distance of 2,400 km. While this study indicated that eels mainly remain in shallower depths during their initial migration route along the continental shelf, researchers discovered that once in the open ocean, eels exhibit a distinct pattern of diel vertical migration (DVM) down to depths of 700 m (Béguer-Pon et al. 2015). Likewise, data retrieved from the European eel study also revealed a marked DVM pattern, primarily between the depths of 200 - 1,000 m (Righton et al. 2016). Researchers propose that this may be a thermoregulation strategy, whereby the lower temperatures encountered at depth help facilitate the delay of gonadal maturation until individuals arrive at the spawning area (Aarestrup et al. 2009). Of note, while this oceanic migratory phase is thought to last no more than six months, it may possibly involve distances of up to 8,000 – 10,000 km for some individuals (WWF 2021; Righton et al. 2016).

Figure 2: European eels becoming pigmented, transitioning from glass eels to elvers in the Shannon estuary, Ireland – Photo Credit: European Eel Foundation

As noted above, anguillid leptocephali metamorphosize into glass eels once they reach their recruitment areas along the continental shelf; this transformation changes their physical appearance so that they now resemble a miniature version of their adult form. To begin with, they are still quite transparent, but as they disperse inland, into the myriad of waterways and streams, they start to develop pigmentation and are then referred to as elvers. This is then followed by another phase of development, during which they are referred to as yellow eels due to the development of a yellowish hue on their bellies. While the term ‘yellow eel’ is universally used to describe this developmental stage, this is not strictly accurate since underbelly coloration may vary from yellow, to white to light grey (Kloppmann 2003). It is in this later developmental stage that sexual differentiation occurs, a process that is significantly influenced by environmental factors (CCAR 2020). Potentially, sex determination may also be density-dependent, with dense populations often being male-dominated (Degani 2016). Eels appear to be negatively phototrophic, thus they prefer dark habitats. They also have an acute sense of smell, which helps them hunt nocturnally for prey items, such as worms, grubs, fish eggs, small fry, caterpillars and frogs. Eels can also survive out of water for ~24 hours, enabling them to travel over land in wet vegetation, making it possible for them to reach landlocked pockets of water (Bergmann 1978). They will remain in this developmental stage, as yellow eels, for many years, the duration of which is dependent on a range of environmental factors. The average lifespan of a European eel is 13 years (Pike et al. 2020a), for American eel it is 12 years (Jacoby et al. 2017) and for the Japanese eel it is somewhat shorter, at 8 years (Pike et al. 2020b). However, instances of much greater longevity have also been mentioned in literature, such as one European eel that lived for around 90 years (Tesch & Thorpe 2003b; Netzler 1928; Dekker et al. 1998). When it is time for adult eels to retrace their earlier voyage, and return to their oceanic spawning grounds, they enter a final developmental stage, known as the silvering process: the first step in their transition to sexual maturity. During this phase, their abdomen takes on a metallic hue and their eyes enlarge; they also stop eating (Hamidoghli et al. 2019) and their digestive tract degenerates (Freese et al. 2019). The cues that trigger the one-way migration of silver eels back to the spawning grounds seem to be linked to lunar phases, although other processes, such as decreasing temperature, increased stream flow, and micro-seismic oscillations caused by low pressure areas over the ocean would also appear to be involved (Tesch & Thorpe 2003b). Gonadal maturation is inhibited during the silvering process and only appears to resume when individuals come within close proximity of the spawning grounds. Although it is assumed that adult eels are semelparous, meaning that they spawn only once and then die, this is still unproven as a spawning event is yet to be observed and documented (SSC 2021; Jarvis 2020).

The IUCN listing for *A. anguilla* notes that the continental distribution of this species covers an area of approximately 90,000 km^2; this incorporates northern Scandinavia, most of Europe's inland waters, all Mediterranean coasts, as well as parts of North Africa (Pike et al. 2020a). *A. anguilla* occurs in all rivers connecting to the Baltic Sea, North Sea, Atlantic Ocean, and Mediterranean Sea but has been extremely rare in rivers connecting to the Black Sea (e.g., the Danube and southern Russian rivers). Also of note, artificial stocking has occurred into the Danube, and in Russia as far east as Orenburg (Dekker & Beaulaton 2016a). By comparison, *A. japonica* is primarily native to Japan, China, Hong Kong, South Korea, Taiwan and Vietnam, although restocking/translocation efforts mean that it is difficult to determine the species' true range in these localities (Gollock et el 2018). The IUCN listing for *A. japonica* also notes that it is a rare vagrant in some other Asian countries: Philippines, Thailand and possibly also Cambodia and Micronesia. These vagrants are located in areas outside of the influence of the ocean currents, thus scientists surmise that their contribution to the ongoing population is possibly minimal (Pike et al. 2020b). With regards to *A. rostrata*, this species' extensive continental range stretches from west Greenland in the north, southward along the Atlantic coastline of Canada and the US, and then westward throughout the Caribbean and much of the West Indies, as well as incorporating the northerly part of the Atlantic coast of South America. This listing also notes that dam construction in the North American continent has greatly reduced this species' range in regions where it was historically abundant (Jacoby et al. 2017). Also of note, all *Anguilla* spp. are considered to be widespread and panmictic, thus all individuals in each respective species are believed to arise from one single, collective spawning stock (Enbody et al. 2021; McCleave et al. 2016; Shiraishi & Crook 2015); this is particularly interesting in consideration of the fact that the spawning areas of the European and American eel are partially sympatric, and yet reproductive isolation between both species has been maintained – except almost exclusively in Iceland, where a low frequency (~10%) of hybridization between European and American eels has been observed (Pujolar et al. 2014).

The development of eel aquaculture

Although commercial eel farming in Japan dates back to 1890-1900 (Shiraishi & Crook 2015), early pioneering efforts towards closing the lifecycle of anguillids did not commence until the 1960s. French and Danish scientists were notably at the forefront of research on the reproduction of European eels (Tsukamoto & Kuroki 2014) whereas Japanese scientists were focusing on the captive reproduction of Japanese eels at this time. In the 1970s, Japanese researchers successfully produced *A. japonica* larvae (Masuda et al. 2012) and, during the 1980s, Russia was the first country to document the successful hatching of *A. anguilla* (Tsukamoto & Kuroki 2014). Despite these early breakthroughs in artificial propagation, however, modern eel farms are still 100% reliant on wild-caught glass eels to stock their systems, since multiple bottlenecks to achieving commercial success in hatchery production are yet to be overcome (Hamidoghli et al. 2019).

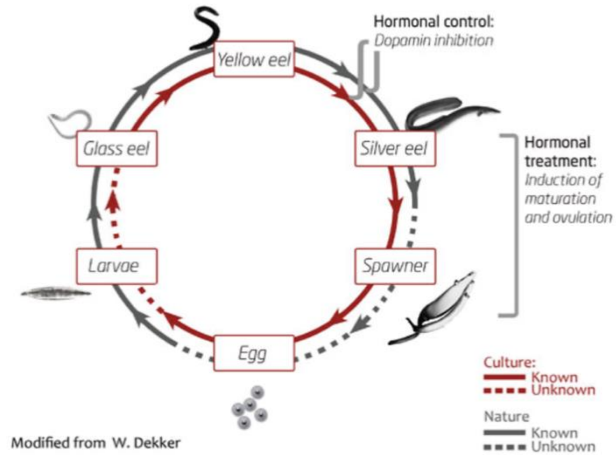

Figure 3: The six transformational stages of the Anguillid lifecycle, showing the status of knowledge pertaining to natural and cultured settings for *A. anguilla* (PRO-EEL 2014)

In recent years, an increasingly greater proportion of anguillids consumed by humans are farm-raised: 2019 production data from FAO indicate that 97% are farmed whereas 3% are wild-caught (FAO 2021). However, since eel farmers are still 100% reliant on wild-caught glass eels to stock their systems, this factor, in conjunction with conservation concerns, means that a great deal of contemporary research and development has been ongoing in the field of artificial eel propagation, particularly in Japan. While Danish researchers have made some progress in their efforts to develop hatchery technology for *A. anguilla* (Eurofish 2020; Tomkiewicz 2012), to date, the most significant progress has been achieved by Japanese researchers, who finally succeeded in closing the life cycle of *A. japonica* in 2011, successfully raising two generations of eel in captivity (E360 2013; Masuda et al. 2012; Tomkiewicz 2012). Despite this, the techniques thus far developed are still not sufficiently advanced to facilitate mass production of glass eels on a commercially viable scale that fulfils the requirements of the eel farming sector (Righton et al. 2021). This important distinction means that eel farming is significantly different to most other modern aquaculture sectors, which are able to operate entirely independent of wild stocks.

Although Japan has historically been at the forefront of eel aquaculture in East Asian, China became the leading producer in the 1990s. While there was some degree of commercial eel farming activity in China in the 1970s, it was not until the Chinese State Council General Office released a '*Notification of the development of eel production and regulation of eel fry export*' in 1986 that the Chinese eel farming sector started to produce significant volumes (Shiraishi & Crook 2015). The first Chinese production of freshwater eels to be reflected in FAO data was in

1989, when 60,000 MT was reported, a quantity which immediately eclipsed the production volumes reported by Japan and Taiwan, both of which had dominated the global anguillid sector prior to this year (FAO 2021; Tsukamoto & Kuroki 2014).

Dynamics of the global glass eel value chain

Because eel farming is still 100% reliant on wild-caught juveniles, this has significant ramifications in terms of the environmental impacts that are attributable to the sector, particularly since a sharp decline in the abundance of global eel stocks has been observed in recent decades (Wold 2018). Although stock declines are well-acknowledged (Deinet et al. 2020; Kaifu & Yokouchi 2019; Gollock et al. 2018; ASMFC 2017) the continued abundance of eel in many localities is such that glass eel fisheries are ongoing in many countries, and some have introduced various management measures, such as catch quotas. While some of these quotas are used for restocking (translocation) purposes, such as in localities where local eel populations have been extirpated, a great deal of these captured glass eels are traded into East Asia to supply eel farms. Since legally procured quantities of the glass eel stage of temperate species falls far short of the demand of East Asian eel farms, illegal trade has become rife and is synonymous with glass eel supply chains (Shiraishi 2020). Since there is both an ongoing legal and illegal trade in glass eels, it is challenging to identify trafficked eels from legally sourced eels. To further complicate matters, European, Japanese and American eels are all morphologically extremely similar, meaning that DNA barcoding is the only sure way to identify one species from another, a procedure that is both time consuming and expensive (Pinchin 2021; CITES 2018a). New forensics tools are in development, however, that may improve this situation (Cardeñosa et al. 2019).

Modern eel farming in Europe started around the 1970s; initially conducted in artificial outdoor ponds, production had largely transitioned to indoor recirculating systems by the 1980s (Dekker & Beaulaton 2016a; Blom 2013). For the last two decades, however, production from this sector has been on a steady decline - as has the number of farms involved (Fletcher 2018; Musing et al. 2018). Although some commercial freshwater eel farming still takes place in Europe, the vast majority of global production comes from farms in East Asia (Shiraishi & Crook 2015), where production has grown exponentially in recent years. In 2019, FAO data show that the combined quantity of cultured European, Japanese and American eels amounted to 271,255 MT – and that this comprised 99.85% of all cultured anguillids (FAO 2021)[18]. The vast majority of this production (98%) took place in East Asia, all of which was reported as Japanese eel (see Figure 7 below), while the balance of production (2%) is recorded as European eel cultured within the natural distribution range of this species (i.e., Europe and North Africa). Of note, none of this production is recorded as American eel (FAO 2021)[19].

[18] Note that the total global production of cultured anguillids in 2019 was 271,659 MT. Of this, 0.15% (i.e., 404 MT) was comprised of species that are not discussed in this assessment – i.e., river eels nei (not elsewhere included) (FAO 2021).

[19] Only 89 MT of farmed American eel has ever been recorded in FAO data, all of which was reported by the Dominican Republic in the late 1980s and mid 1990s (FAO 2021).

However, as noted above, these three species are very difficult to tell apart and studies that have scrutinized the dynamics of the global eel trade clearly demonstrate that a large proportion of East Asian farmed eel is in fact comprised of *A. rostrata,* some of which has been legally sourced and traded and some of which has not, as well as *A. anguilla* - all stages of which it is currently illegal to trade out of or into the EU, and the glass eel stage of which it is currently illegal to trade out with all other countries within this species natural distribution area (Nijman & Stein, 2021; Pavitt et al. 2021; UNODC 2020; Kaifu et al. 2019)[20]. Thus, while FAO data indicate that only Japanese eel is farmed in East Asia, it is evident that much of this production has been inaccurately reported, species-wise, and is actually comprised of European as well as American eel. Of note, while FAO aquaculture production statistics – which date back to 1950 - currently identify all present and historic East Asian farmed eel production as being solely comprised of Japanese eel (FAO 2021), this evidently has not always been the case, as indicated in Dekker (2004), which states that production was generically recorded as 'river eel' at this earlier time. Contrary to these contemporary FAO statistics, trade statistics and customs data show that European glass eels were flown into Japan for farming purposes as early as 1969 (Briand et al. 2007; Egusa 1979), as were American eels, which were first shipped from the US State of Maine to Japan in the 1970s (Ebersole 2017; ASMFC 2012). While exports of European glass eels to Japan declined in the mid 1970s (Egusa 1979) and evidently ceased in 1982, due to high mortality rates, a surge in exports to East Asia occurred in 1990s, when China's eel farming sector started to develop rapidly (Shiraishi 2020; Briand et al. 2007).

In addition to uncertainties about the provenance and legality of glass eel imports used to stock farms in East Asia, domestically sourced Japanese eel stocks are also subject to poaching. In Japan, for example, Kaifu et al. (2019) estimate that only around half of the glass eel catches are reported accurately, thus many of the eels in Japanese aquaculture originate from illegal and unreported fisheries. Of additional note, several non-native eel species, including *A. anguilla* and *A. rostrata* have been reported in Japanese waters, albeit not recently. While some of these non-native eel may have escaped from culture facilities, others were also deliberately released with the aim of enhancing local fisheries (Arai et al. 2017). Likewise, *A. rostrata* has been found in the wild in Taiwanese waters (Tzeng et al. 2009) and it is possible that this is also the case in other East Asian eel farming countries.

Despite the evident shortage of locally available Japanese glass eel stocks, the preferred species for consumption in East Asia (Gollock et al. 2018; Chambers et al. 2016a), the eel farming sector in East Asia has been able to sustain itself via the development of alternative global glass eel supply chains. Since eel is one of the most valuable fish species in the East Asian region (Hamidoghli et al. 2019; FAO 2005), this demand has evidently proven to be extremely lucrative for wild collectors in many other countries – whether such collection has been legally endorsed or not.

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[20] For reference, note that the export quotas set by countries can be checked using CITES Export Quota Tool: https://cites.org/eng/resources/quotas/export_quotas?field_country_target_id=All&field_species_target_id=Anguilla+anguilla&field_date_value%5Bmin%5D=2000-01-01&field_date_value%5Bmax%5D=2021-12-31

To put this into perspective, it is worth considering the elver fishery in the State of Maine, which is the only commercial fishery of its type in the US (Flaherty 2018)[21]. In 2012, Maine's glass eel harvest amounted to 21,611 pounds (9.8 MT); cumulatively, this catch was valued at US$40,384,618, which equates to US$1,869 per pound on average[22]. However, the price per pound fluctuates from year to year, dependent upon supply and demand; in 2018, the average value of legitimately sourced Maine elvers rose to US$2,366 per pound, increasing to US$3,000 in 2019 (USFWS 2019). In response to concerns about the health of the eel stock, a quota system was introduced in 2014; initially set at 11,479 pounds (5,207 kg) it was later revised downwards to 9,688 pounds (4,394 kg) the following year, and this 2015 quota has remained in place ever since (pers. comm. Kirby Rootes-Murdy, Senior Fishery Management Plan Coordinator, Atlantic States Marine Fisheries Commission, March 2021). Despite such management strategies, however, the demand of eel farms in East Asia is such that illegal glass eel collection is a persistent occurrence, both in the US and elsewhere (Ebersole 2018).

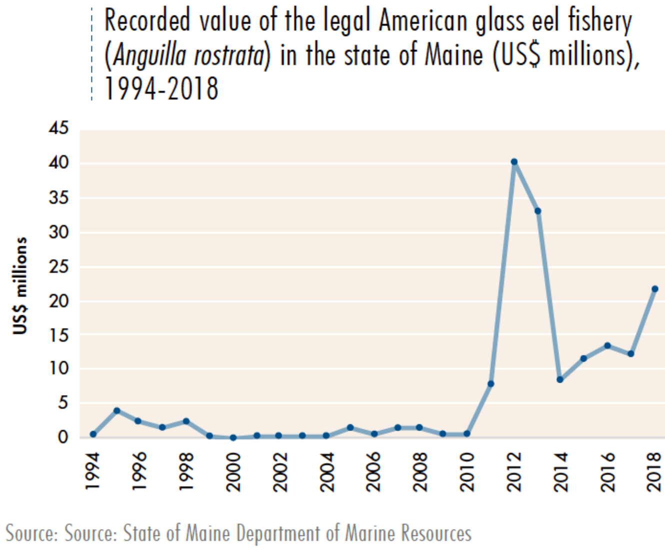

Figure 4: Value of the American glass eel fishery in the US State of Maine, 1994 – 2018 (UNODC 2020)

In conclusion, since eel farming in East Asia gives rise to significant amounts of European, Japanese and American eels being trafficked, this factor – a most unusual aberration within the wider context of global aquaculture - must be considered pivotal in this Seafood Watch Assessment. For this reason, this report update primarily focuses on Criterion 8X: Source of Stock – independence from wild fisheries, in which the wildlife trafficking associated with East Asian eel farming is explored in greater detail. Since C8X is the priority Criterion in this assessment update – which has resulted in a Critical rating – the other Criteria have been retained in their original (2014 report) format, for reference. Note that the original report was written in conformance with Version 2 of the Seafood Watch Standard for Aquaculture.

Cultivation of eels in East Asia: An overview of production systems

Since wild glass eels or elvers are used to stock aquaculture systems, the first stage of the culture process involves quarantining incoming fry, to ensure that they do not spread diseases

[21] Note that while Maine has the only commercial glass eel fishery in the US, small quantities of elvers are also legally harvested from one river in South Carolina, although only a few individuals have permits for this activity; elsewhere in the US it is illegal to catch elvers (pers. comm. Nick Walker, Ph.D., Conservation Biologist, March 2021).

[22] https://www.maine.gov/dmr/commercial-fishing/landings/documents/elver.table.pdf

Open field pond culture in China

Tank culture in Korea

Open field pond culture in Chinese Taipei

Figure 5: Some of the different eel farming systems used in East Asia (AJASEA 2016)

to the rest of the farm. Juvenile eels are also weaned onto artificial diets at this time (TFS 2009a). A number of different on-growing systems may be utilized, depending on the location of the farm and the level of investment available. These range from traditional outdoor earthen ponds (lined or unlined) to concrete tanks, through to more intensively stocked and managed indoor facilities that use some degree of water recycling. Production of eels in Europe mainly takes place in recirculating aquaculture systems (RAS), with 80% of farms reportedly using this technique (Fletcher 2018), utilizing indoor fiberglass or cement tanks (TFS 2009b). While some full RAS systems also appear to be employed in the production of eels in East Asia, no quantitative data regarding the degree to which such systems are in use was identified.

A review of the global status of eels notes that intensive eel production in China takes place in indoor facilities, using water recirculation, although some production still takes place in outside ponds (Tsukamoto & Kuroki 2014). In Taiwan, while RAS is reportedly not commonly used in aquaculture, some degree of water re-use is typically implemented in eel culture. Evidently, by the 1990s, eel farming practices in Taiwan had caused an excessive depletion of ground water, which in turn caused soil salination and extensive land subsidence, thus reuse of water was instigated in order to mitigate these impacts. In Taiwan, ponds are also set aside to collect rainwater for eel farming (Tsukamoto & Kuroki 2014). In 1997, due to concerns about freshwater resources, South Korea implemented a government policy that changed the requirements for eel farmers and effectively made farms relocate into indoor facilities that used flow through, or some degree of recirculation (TFS 2013). A recent South Korean paper notes that the country’s eel sector, which originally utilized earthen ponds, has now transitioned to using RAS (Hamidoghli et al. 2019). In Japan, most eel aquaculture had already transitioned from outdoor ponds to indoor systems by the early 1970s (Tsukamoto & Kuroki 2014). While it is assumed that some degree of water circulation takes place in these indoor units, it does not appear that full RAS systems are common, although a recent feasibility study into the use of zero emissions RAS for eel culture was identified, possibly indicating that this may become more commonplace in future (Suzuki & Maruyama 2017).

Figure 6: An eel farm in Japan – ponds are kept at 28°C and are covered in transparent plastic insulation (AJASEA 2016)

Eel diets have a high fishmeal content of around 65-70%, a crude protein level of around 50%, and a high carbohydrate level of around 22%. Common ingredients included in eel feed, in addition to fishmeal, are vegetable or animal fat, corn, wheat, soybean meal, yeast, starch, dicalcium phosphate, plus trace mineral and vitamin premixes (TFS 2009a). Feed ingredients are combined with water and fed to eels as a paste (AJASEA 2016). Of note, China's biggest eel feed producer is Fujian Tianma Science and Technology Group Co[23].

Industry statistics and the scale of the cultured eel sector in East Asia

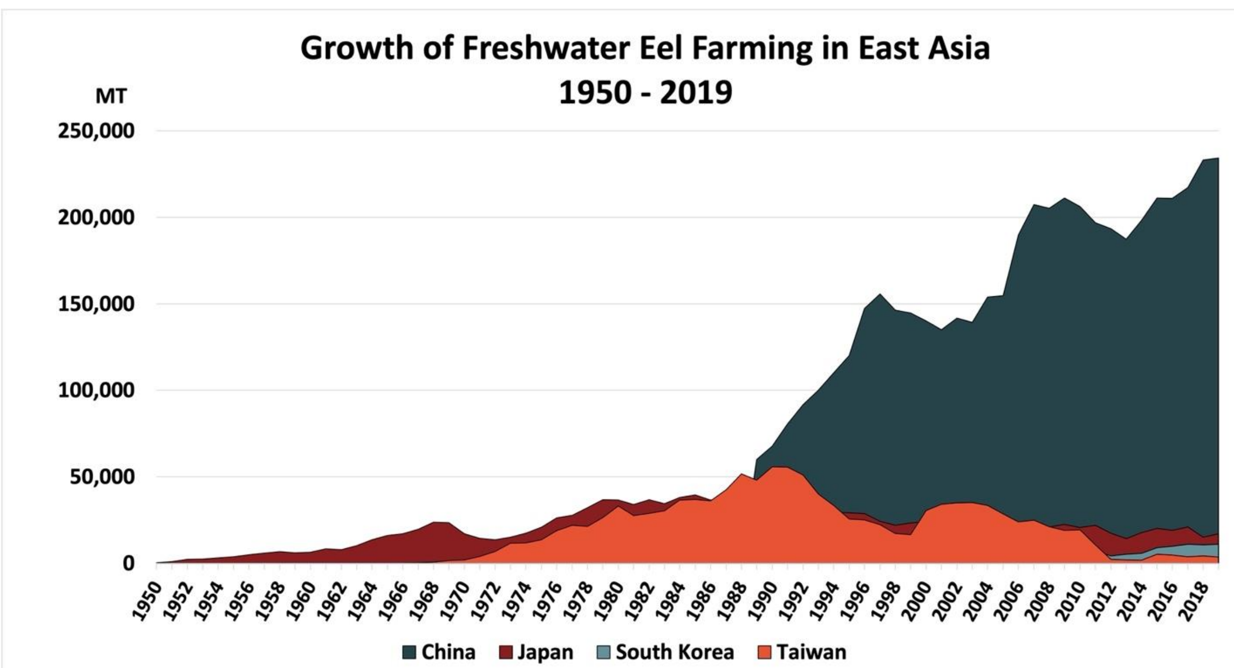

Figure 7: Growth of Freshwater Eel Farming in East Asia 1950 **–** 2019 (FAO 2021)

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[23] https://www.seafoodsource.com/news/business-finance/tianma-reports-higher-profits-on-expansion-into-eel-aquaculture

As is apparent in Figure 7, cultured eel production has increased steadily over the last three decades in East Asia, where the vast majority of global eel farming (98%) takes place, primarily in China. In 2019, 265,759 MT of eels were farmed in East Asia, of which 234,223 MT (88%) was produced in China (FAO 2021).

As noted above, all cultured eel production from China, Japan, South Korea and Taiwan is currently recorded as Japanese eel in FAO statistics, whereas the balance of documented global production primarily pertains to European eel farmed in Europe and North Africa. In 2019, this latter amount equated to 2% of total global eel production reported to FAO for that year, all of which was produced in Europe and North Africa. Although American glass eels have evidently been shipped to East Asia for farming purposes for a number of decades, only 89 MT of cultured American eel has ever been reported to FAO - all of which was reportedly produced in the Dominican Republic in the late 1980s and mid 1990s. Likewise, European eel has evidently also been farmed in East Asia, even though East Asian production of this species has never been officially reported to FAO.

Although China is presently by far the world's largest producer of eels, Japan has historically been the region's most prodigious producer and consumer of them, with a tradition of eel consumption dating back centuries (Tsukamoto & Kuroki 2014) and farming practices that date back 120 years (Egusa 1979). FAO Customs and trade data indicate that Japan's eel consumption in the early 2000s equated to 70% of global production at that time (Shiraishi & Crook 2015). However, Japan's eel consumption has declined markedly since then and both domestic production and importation of eel meat has decreased. It has been suggested that this decline may be due to reports of fraudulent labelling of origin compounded with the reported use of banned chemicals, including malachite green, furazolidone, dicofol and endosulfan, on Chinese eel farms. Malachite green, for example, has been classified as an unapproved aquaculture drug that has been recognized as a human health concern by the US Food and Drug Administration (FDA 2021, Nijman & Stein 2021). Even so, between 2016 - 2020 Japan was still the principal importer of Chinese eel products, absorbing 52% of China's prepared and preserved eel exports, according to Chinese Customs data (ITC 2021) (see Figure 9).

While China does not appear to share Japan's long tradition of eel consumption (Gollock et al. 2018), an extrapolation of FAO data seems to suggests that it has become the primary global consumer of eel products since 2007 – however, experts note that caution is needed while considering Chinese eel production and consumption data. Experts have identified that different data sources pertaining to eel production and consumption volumes in China vary greatly, which in turn makes it challenging to accurately determine these amounts (Shiraishi & Crook 2015). Elsewhere, South Korea has reportedly increased its eel consumption and other emerging markets have also given rise to greater demand for eel products – most notably Russia, Taiwan and the US (Shiraishi & Crook 2015).

Import and export statistics of eels farmed in East Asia

US eel imports

While US trade data do not disaggregate eel imports at the species level, or distinguish cultured products from wild, it is possible to gain a general overview of cultured Aguillidae imports by focusing on those trade flows that originate from East Asian eel farming nations only. These data, which are presented in Figure 8, show that annual eel imports have commonly been in the 5,000 to 6,000 MT range in recent years – although it should be noted that only unambiguous eel product Harmonized Tariff Schedule (HTS) codes have been included here, thus this data set can only be considered to be indicative of actual eel import volumes, not definitive[24]. This is an important factor to consider, since such trade code ambiguity contributes to a lack of transparency in the eel value chain: of note, a recent international wildlife trafficking study identified 72 different, partly overlapping, codes pertaining to eel products (UNODC 2020).

The aggregated average values for these six years indicate that 95.6% of US eel imports come from China, 2.1% from Taiwan, 1.6% from Japan, and 0.7% from South Korea (NOAA 2021). It is notable that these trade data indicate a marked decline in imports during 2020, particularly with reference to imports from the dominant supplier, China, which supplied 2,512 MT of eel products to the US in 2020. While this decline is consistent with the COVID-19 pandemic trade disruption that has impacted many sectors, it is also likely that these trade figures may be revised upward somewhat when this year's data set is fully updated; for example, an upward adjustment of 4.5% was noted in 2019 East Asian eel import statistics, when data extracted in 2020 was compared to data extracted the following year.

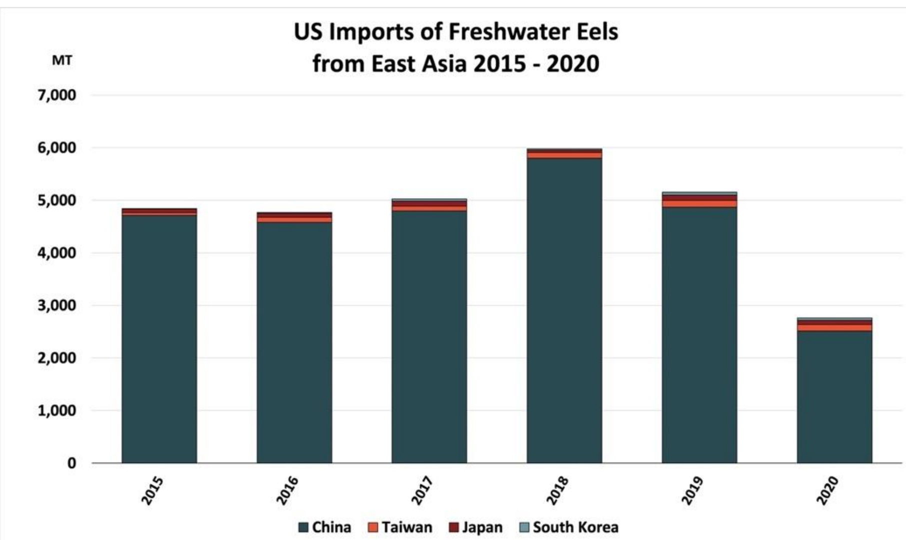

Figure 8: Eel imports from East Asia (2015 to 2020) – these NOAA Foreign Fishery Trade Data clearly identify China as the principal source of eel imports into the US (NOAA 2021)

[24] Data included in Figure 8 pertain to HTS codes that explicitly refer to eel products only – i.e., 302740000, 303260000, 1604171000, 1604174000, 1604175000, 1604176000, 1604178000. However, a further nine HTS codes that can also pertain to imported eel products were omitted; these codes refer to a variety of product forms in which the specific species are not identified, and a range of possible species are described, including carp, catfish, eels, Nile perch, snakehead and tilapia - for example, HTS code 304690000 applies to '*carp, eels, snakehead fillet frozen*'.

As noted earlier, although the entirety of East Asian farmed eel production is reported to FAO as *A. japonica*, it is evident that some of this amount is comprised of *A. anguilla* and *A. rostrata*, since it is evident in Chinese Customs data that glass eels of both of these species are imported for use in Chinese eel aquaculture (Nijman & Stein 2021). To try and better understand the species breakdown of US imports, Seafood Watch reached out to several regional seafood suppliers across the US, which collectively service thousands of accounts in the restaurant, hospitality, and retail sectors across the country. The consensus of these suppliers was that the overwhelming majority of (if not all) eel imports come from China; these are labelled as 'unagi' and although no species information is provided on these products, suppliers are under the impression that the species is *A. japonica*. Suppliers also commented that there is some seasonal (Christmas) trade in US live wild-caught *A. rostrata* sourced from US fishermen, although the amounts are very small.

<u>Chinese export markets for farmed eel</u>

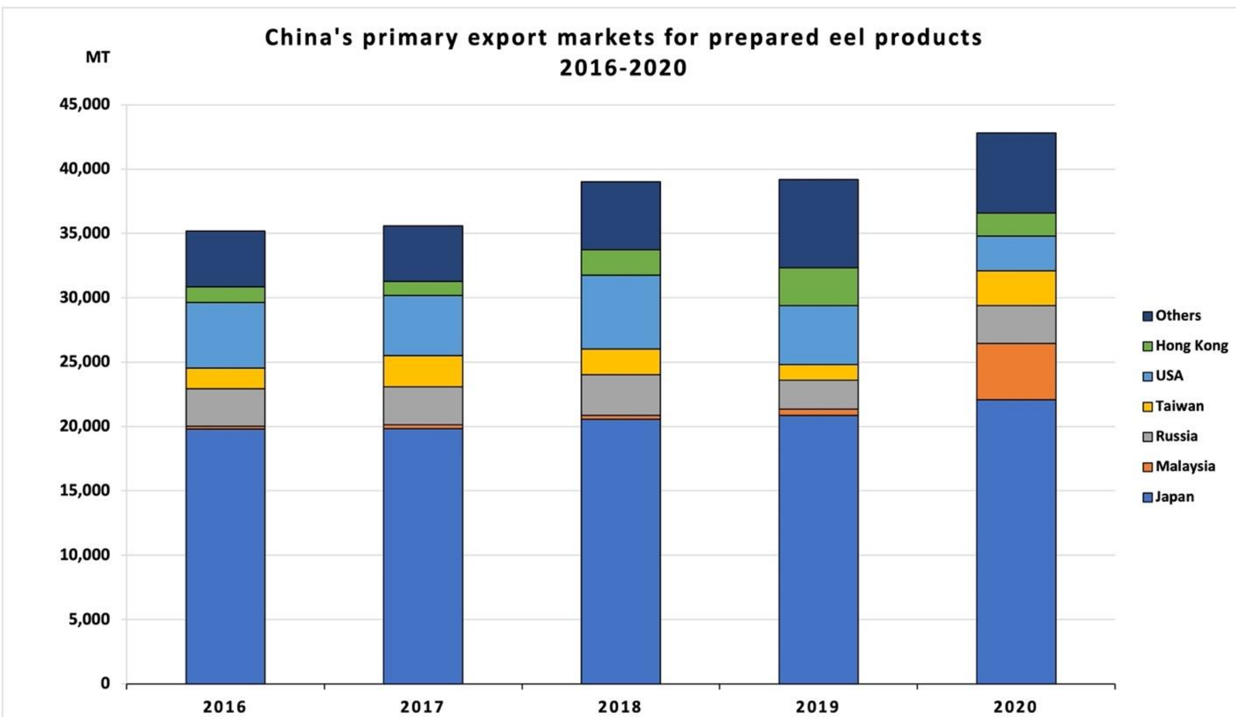

Figure 9: Principal countries importing eel products from China (HTS code 160417: Prepared or preserved eels, whole or in pieces - excluding minced) Data sourced from General Customs Administration of China/UN Comtrade (ITC 2021)

The primary export markets for eel produced in China, as per Chinese Customs data, are shown in Figure 9. As can be seen, Japan has consistently absorbed over half of China's eel exports during this timeframe. In consideration of 2020 export data alone, Japan accounts for 52% of the total, Malaysia 10% (note that Malaysia appears to have emerged suddenly as a major market only in 2020, according to these data), Russia 7%, Taiwan and the US both account for 6% each, Hong Kong 4%, and the rest of the world cumulatively absorbs the balance of 15% (ITC

2021). Of note, the specific volume of exports from China to the US indicated in Figure 9 is 2,696 MT, which is similar to the 2,512 MT of US eel imports indicated in NOAA Foreign Fishery Trade Data above (i.e., Figure 8).

As can be seen in Figure 10, Japan's share of Chinese eel exports was even higher in the past. By comparison, in terms of global production FAO data indicate that in the early 2000s Japan consumed approximately 70% of global Anguilla production but that by 2007 China superseded Japan as the world's principal market for eel. However, as noted above, some authors have commented that it is hard to accurately determine eel production and consumption volumes in China since different data sources provide varying figures (Kaifu et al. 2019; Shiraishi & Crook 2015).

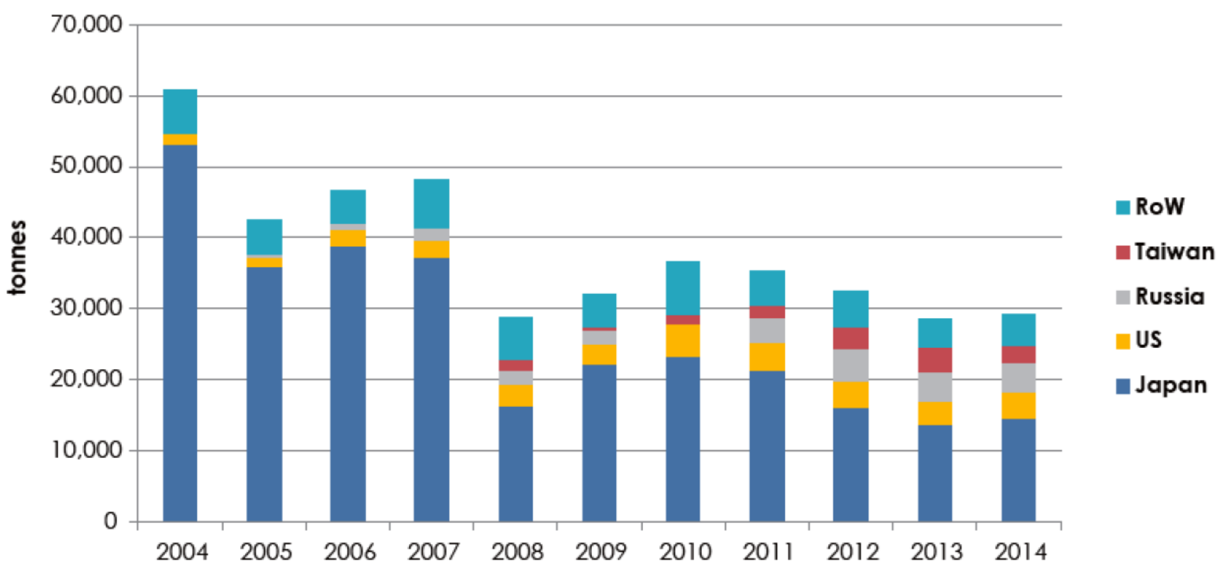

Figure 10: Chinese exports of prepared/preserved eel by destination country from 2004 to 2014, shown in metric tonnes (MT) - Source: Chinese Customs data, as depicted in TRAFFIC Report (Shiraishi & Crook 2015) - Note that export destinations absorbing under 1000 MT, plus exports to Hong Kong, are included as RoW (Rest of the World)

Looking to the future: Transparently sourced eels

It is evident that there are many discrepancies inherent in industry statistics pertaining to the cultured eel sector; customs, trade and production data do not correlate well with one another. Given the numerous intermediaries involved, compounded by the thriving black-market in glass eels that the sector is inextricably linked to it, this is perhaps unsurprising. For this reason, experts that have studied the complex dynamics of this value chain advise that a high degree of caution is needed when analyzing and interpreting eel industry statistics (Shiraishi & Crook 2015). Some recent developments are underway, however, which are helping to improve the traceability and transparency of eel value chains in some jurisdictions.

The Sustainable Eel Group

Established in 2010 and headquartered in Brussels, the Sustainable Eel Group (SEG) is an organization whose stated mission is to accelerate the recovery of the European eel. As part of their toolkit, SEG have developed a standard and certification program, which covers four different elements of the commercial eel sector: fishers, traders, farmers and processors. Through this voluntary certification and assurance scheme, SEG aim to ensure that participating entities comply with best practices and that the eel products they supply are fully traceable, as per the SEG standard[25]. SEG, who are partially funded through grants and partially through the commercial eel sector, have already certified a substantial proportion of eel production within the EU. However, a zero import/export policy for European eel has been in place within the EU since 2010, pursuant to this species' CITES Appendix II listing, thus sales of these certified eel products are presently restricted to inside of the EU only. (For more information on the European eel's CITES status and the implications of this, see the section 'Management of temperate eel stocks in their respective continental ranges' in Criterion 8X: Source of Stock.)

Similarly, certified American eel products may also become available in the near future; SEG is currently collaborating with eel experts and scientists in the US to adapt the SEG Standard to the domestic *A. rostrata* sector (pers. comm. David Bunt, Director of Conservation Operations, Sustainable Eel Group, March 2021). Unlike East Asia and Europe, the Americas do not have a tradition of eel farming (Jacoby et al. 2017) and eel farming in the US is a limited and nascent activity. With regards to reported volumes of cultured American eels, the only country to ever register farmed production of this species with FAO was the Dominican Republic; these FAO data indicate that this nation produced a total of 89 MT during the late 1980s and early 1990s (FAO 2021). Interestingly, a small quantity of *A. rostrata* glass eels was imported into the EU recently from North America for aquaculture purposes (Musing et. al 2018) – although no further developments in this regard have been noted in the literature. Furthermore, although initial attempts to farm this species in the US and Canada evidently failed, more recent eel farming initiatives in both nations are reportedly gaining traction (CCAR 2020).

Eel farming developments in North America

Since 2016, the University of Maine has been collaborating with a local commercial start-up: a land-based eel farm called American Unagi[26, 27, 28] (Hein 2020; ANA 2019; BDN 2019; Case 2018; NPR 2018). In 2018, the State of Maine granted American Unagi a 200 pound[29] (90 kg) annual glass eel quota for aquaculture stocking (Pinchin 2021; ASMFC 2020). Similarly, in Nova Scotia, an industry-academic partnership between Dalhousie University and NovaEel Inc.[30], is seeking to develop a local, land-based eel farming business, with research particularly focusing on the production of all female eels through the implementation of a feminizing process (Cohen et al.

[25] https://www.sustainableeelgroup.org/seg-standard/
[26] https://www.americanunagi.com
[27] https://youtu.be/LNWCAbUtGf4
[28] https://www.seafoodsource.com/news/premium/aquaculture/american-unagi-breaks-ground-on-usd-10-million-eel-aquaculture-facility-in-maine
[29] http://www.sargassoseacommission.org/storage/US_Country_Presentations_updated_Final.pdf
[30] https://www.smithsonianmag.com/science-nature/eel-fortune-180968028/

2017). Although the reasons are as yet unclear, most farmed eels become male rather than female (Tsukamoto & Kuroki 2014). Researchers note that females can attain a weight of several kilos, in contrast to males, which only grow to around 150g, thus production of females greatly improves the possibility of achieving a commercially viable industry[31].
In addition to the aforementioned US eel farming initiative, there are evidently seven eel farms registered in the US[32], according to the USDA's most recent '2018 Census of Aquaculture'[33]. One of these is likely Aqua Vida, a company based in Florida, which aims to farm African eels (*Anguilla mossambica*) in Michigan[34, 35] using RAS technology, the company's website describes this species as: "*The last remaining temperate eel species with a pristine and unexploited wild population*"[36].

Another source of American eel available on domestic US markets comes from small ranching-style operations that do not involve glass eels; these operators buy locally sourced yellow eels at around 0.5 - 0.9 pounds (~225g - 400g) and subsequently on-grow them to around 2 - 3 pounds (~900g - 1,350g). The production volume realized by these activities is in the hundreds of tonnes (pers. comm. Nick Walker, Ph.D., Conservation Biologist, March 2021).

Common Names for eels

Anguilla japonica: Japanese Eel, unagi
Anguilla anguilla: European Eel
Anguilla rostrata: American Eel
Collectively, Anguillids are known as freshwater eels or river eels

Product Forms

The primary product forms in which freshwater eels are sold in are: live, fresh, whole, frozen, H&G (headed and gutted), steaks, fillets, and smoked. In Japanese cuisine, freshwater eel, particularly Japanese eel, is called 'unagi'. Some common dishes prepared with unagi include kabayaki , shirayaki, hitsumabushi, eel nigiri sushi, and eel hone senbei. In addition to freshwater eels, Japanese cuisine also features conger eels, called '*anago'*, and pike conger eel, called '*hamo',* which are not in the family *Anguillidae*[37].

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[31] https://www.dal.ca/news/2017/08/02/dalhousie-researchers-help-ns-company-launch-eel-aquaculture-bus.html
[32] https://www.nass.usda.gov/Publications/AgCensus/2017/OnlineResources/Aquaculture/aqua100200020.pdf
[33] https://www.nass.usda.gov/Publications/AgCensus/2017/Online_Resources/Aquaculture/index.php
[34] https://news.jrn.msu.edu/2019/01/proposed-eel-farm-raises-concerns-about-invasive-species/
[35] https://eu.lansingstatejournal.com/story/news/local/2021/09/15/eel-farm-project-st-johns-aqua-vida-icell-delayed-pandemic-financing/8258728002/
[36] http://avidallc.com
[37] https://savorjapan.com/contents/more-to-savor/unagi-and-anago-8-wonderful-ways-to-eat-japanese-eel/

Criterion 1: Data quality and availability

In the previous eel report, which was published in 2014, the Source of Stock Criterion received a moderate data score due to the ambiguous origins of eel fry used to stock eel farms in East Asia. While there is still little transparency surrounding the provenance of eel fry used by the sector, a significant amount of literature has become available, since this sector has come under increased scrutiny in many jurisdictions in recent years. This has helped, somewhat, to elucidate the complexities of the eel value chain and the black-market in glass eels that underpins it.

Numerous bulletins published by TRAFFIC, an NGO that works on matters pertaining to global trade in wild animals and plants, are particularly insightful in this regard. Publications obtained from the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) were also of great relevance in the preparation of this report, especially a recent publication that explored the impact of the implementation of the CITES Appendix II listing of European Eel and the subsequent effect that this has had upon the East Asian eel sector. Valuable data concerning eel trafficking was also obtained from a recent world wildlife crime report published by the United Nations Office on Drugs and Crime. Europol press releases were an important source of data in terms of identifying the extent of trafficking and the increase in law enforcement that has occurred recently.

Additionally, a great deal of useful information and data were also obtained from the numerous eel reports published by the International Council for the Exploration of the Sea (ICES) and the Working Group on Eels (WGEEL), which conducts the annual stock assessment for the European eel. Due to the global nature of the farmed eel value chain, input from eel experts in numerous localities was sought, including East Asia, Europe and the Americas. Extensive personal communications with these experts were of key importance during the preparation of this report.

Significant volumes of data pertaining to the American eel and its status were obtained from the Atlantic States Marine Fisheries Commission (ASMFC) as well as Fisheries and Oceans Canada (DFO), both of which have produced numerous publications concerning this species and its relevance in the East Asian eel farming sector. Although a great deal of well-researched data is now available regarding the source of stock used by the eel farming sector in East Asia, these data highlight the lack of transparency in such value chains. The data presently available is therefore assessed to be moderate-high since many impacts of the eel value chain still remain unknown.

Criterion 8X: Source of Stock – independence from wild fisheries

Brief Summary

One hundred percent of commercially cultured freshwater eel is produced from wild-caught juveniles, therefore the paramount factor this Criterion addresses is the conservation status of the wild stocks from which these seed fry are obtained. While all of the freshwater eel cultured in East Asia is reported to FAO as Japanese eel, it is evident that glass eels of several other species are also often routinely stocked by farmers throughout the region – especially European and American glass eels. To assess this Criterion, therefore, it is imperative to review the status of all three of these eel stocks, and to determine whether they are considered to be endangered, threatened or protected. This is not a straightforward issue, however, particularly since each species is part of one single, wide-ranging panmictic stock. Furthermore, different entities use very different assessment methodologies and differing criteria to arrive at their respective determinations about a species' conservation status; for example, there is often much confusion around the American eel and the fact that it is listed as endangered by IUCN but it is not included on the US' Endangered Species List. While drastic declines and possible extirpation have been noted in many range regions, for all three species considered in this report, in each case there are also some localities in which eel are still considered to be relatively abundant.

The IUCN lists the European eel as critically endangered and the Japanese and American eel as endangered; these determinations are based upon total population decline, a trend that all three stocks exhibit. In addition to having an IUCN critically endangered listing, the European eel is CITES Appendix II listed: in order to trade European eel internationally (i.e., outside of its range states), exporting countries require a positive Non-Detriment Finding assessment (NDF) that enables national CITES authorities to issue CITES trade permissions for export. In line with these requirements, the EU responded by implementing a zero import/export policy for all European eel, while CITES Parties in most other range states responded by explicitly banning the export of glass eels. The Japanese eel is also identified as endangered in Japan, and critically endangered in Taiwan. While authorities in the US and Canada concur that there has been a declining trend in the American eel stock, neither country has deemed that federal protections for this species are warranted, although their respective management and scientific authorities continue to monitor the situation closely. While regulation and monitoring is in place in the northerly range of this species, literature notes that knowledge pertaining to the species' southerly range is somewhat scant.

Although eel farms in East Asia used to be adequately supplied by locally harvested glass eels, the recruitment of Japanese eel has declined significantly in recent decades. While overfishing is thought to be a contributory factor in this decline, a suite of other significant factors are also believed to be at play, particularly blocked migration routes and habitat loss linked to industrialization and other anthropogenic activities. To augment the dwindling supply of locally caught juveniles, the procurement of glass eels for farms in East Asia was subsequently partially

outsourced to fisheries in Europe. However, as with the Japanese eel, similar declines were noted in European eel stocks around the same time. On the advice of scientists, a number of measures were subsequently put in place to protect the European stock, most notably the EU Eel Regulation and the CITES Appendix II listing.

Demand for farmed eel, however, has grown a great deal in recent decades and production in East Asia, especially China, has grown exponentially. This has led to the growth of a thriving international glass eel supply chain, some of which is legal; some of which is not. When international movements of European eel became restricted, and enforcement and monitoring increased, this resulted in a commensurate upsurge in the procurement of the glass eel stage of American eel, a species for which declining abundance indices had also recently been observed – at around the same time as scientists had noted declines in the Japanese and European eel stocks. With this surge in trade, authorities in the US and Canada implemented a range of measures, including quotas, to try and control the fishery. However, the lucrative nature of trading glass eel into East Asia is such that poaching and smuggling activities are rife - and onerous to contain. Legal and illegal American eels are frequently shipped alongside each other, as is also the case with movements of Japanese glass eels within East Asia. This makes it very hard for enforcement agencies to police the glass eel value chain - particularly since these species all look alike. The only definitive way to tell them apart is by performing DNA analysis, however such tools are time consuming and costly to use thus they are seldom implemented in routine trade inspections. Even when DNA forensics tests are implemented, such as in international wildlife crime detection operations, they can only confirm the occurrence of European eel trafficking, since only this species has measures in place to ban the export of the glass eel stage (and all life stages, in the EU) from range states, due to its listing in CITES Appendix II. Since neither the Japanese nor American eel have a status under CITES, this mechanism cannot assist in the detection of criminal acts involving these species, however.

Despite numerous country-level measures to monitor the harvest and sale of Japanese and American glass eels, the overall global failure of these provisions is apparent since trafficking in glass eel of all species is ongoing. Because illegal and legal glass eels are shipped to East Asia together, are stocked and harvested together, and are also subsequently sold and shipped to international seafood buyers together, there is no way for consumers to ascertain if the eel they have purchased is legal or not. Present day eel supply chains are inextricably tainted with illegally-sourced products. A great deal of such trade inevitably goes undetected since there is currently no routine way to tell legally-sourced East Asian eel products apart from those which have been obtained otherwise, via illegal, unreported and unregulated (IUU) fishing. Due to the East Asian eel sector’s total reliance on wild-caught juveniles, all of which are from declining stocks, many of which have been deemed to be endangered and some of which are critically endangered and illegal to trade internationally, this Criterion 8X – Source of Stock is assessed with a deduction of -10 out of -10 and a Critical ranking.

Justification of Rating

Criterion 8X is an exceptional criterion, which is based on the assumption that the majority of aquaculture operations worldwide are operating as closed life cycles with broodstock no longer originating from wild populations. However, if there is sourcing of wild juveniles and/or broodstock that are considered endangered, a Critical score is assigned. The Seafood Watch Standard further qualifies 'endangered' as follows: species from a "*Seafood Watch Red/Avoid fishery,*" or "*Species listed as "protected," "vulnerable," "threatened," "endangered" or "critically-endangered" by the IUCN (Red List) or by a national or other official list with equivalent categories. However, more recent or more regional/stock specific data can override these determinations.*" The following therefore explores the eel value chain, as it pertains to production in East Asia, in light of these parameters.

Why the eel aquaculture model does not operate as a closed life cycle system

As discussed in the introduction to this report, concerted efforts to fully domesticate the eel have been ongoing since the 1960s. However, the techniques thus far developed are still not sufficiently advanced to facilitate mass production of glass eels on a commercially viable scale that fulfils the requirements of the eel farming sector (Shiraishi & Crook 2015; Tsukamoto & Kuroki 2014). This important distinction means that eel farming is significantly different to most other modern aquaculture sectors, which are typically able to operate entirely independent of wild stocks.

A primary bottleneck noted by contemporary researchers is the inability of domesticated eels to achieve sexual maturity in captivity, thus hormonal interventions are used, with varying success. For females, the problem resides with ovulation, rather than oocyte maturation, and it is likely that their poor reproductive performance in captivity may be linked to unfulfilled nutritional requirements in this setting (Righton et al. 2021; Higuchi et al. 2019; PRO-EEL 2014). Likewise, the provision of adequate larval and juvenile nutrition is another challenge that researchers face (Righton et al. 2021). In an oceanic environment, the nutritional needs of wild anguillid leptocephali are fulfilled through the consumption of organic particulate matter suspended in the water column, which researchers refer to as 'marine snow' (Miller et al. 2016). While some success has been obtained using a paste containing shark egg yolk as a larval starter diet, commercially practical diets to support the requirements of eels during early developmental stages have yet to be developed (Hamidoghli et al. 2019, Ayala et al. 2018, E360 2013). As a result, 100% of commercial eel farming is reliant on wild-caught glass eels and elvers[38].

Overview of the status and classification of European, Japanese and American eels

As noted in the introduction to this report, a foremost concern of the East Asian eel sector is the evident lack of transparency surrounding the provenance and legality of the glass eels used to stock farms. Even though there are undoubtably legitimately sourced Japanese and American glass eels raised on East Asian eel farms, there is currently no routine way to tell

[38] Once these willow-leaf shaped leptocephalus larva have dispersed over great distances from their oceanic spawning grounds and have reached the coast, they undergo metamorphosis into a transparent 'glass eel', after which they start to become pigmented and typically start to ascend rivers and streams – they are now referred to as 'elvers'. Note that while the categories of 'glass eel' and 'elver' are not biologically synonymous they are frequently used interchangeably in the literature.

these apart from those which have been obtained otherwise, via illegal, unreported and unregulated (IUU) fishing[39]. Furthermore, while it is possible for non-EU range states to obtain permission to trade European eel into East Asia, most range states have explicitly banned the export of the glass eel stage of this species in response to its CITES Appendix II listing [40]; despite this, large amounts of non-compliant European glass eels are evidently procured by the sector, in violation of the Convention. While Seafood Watch do not assess elver fisheries, since these are not typically used directly for human consumption in North America, a number of other determinants have been identified to facilitate scoring of this Criterion, which are discussed in some detail below.

IUCN listings for Anguillids

Of note, the IUCN Red List of Threatened Species[41] presently ranks both the Japanese and American eel as 'endangered' (EN) and the European eel as 'critically endangered' (CR), further noting that all three species have exhibited a decreasing population trend over the duration of three generations (Pike et al. 2020a; Pike et al. 2020b; Jacoby et al. 2017). Additionally, the IUCN Anguillid Eel Specialist Group (AESG) notes that concerns for all members of the family *Anguillidae* have been mounting over the last 30 years, due to their declining numbers[42].

It is interesting to note that while the European eel is ranked by IUCN as critically endangered, *A. anguilla* is still found widely in European inland waters and is still relatively abundant in many areas, which is evidenced by glass eel recruitment numbers in excess of a billion individuals each year (SEG 2020), particularly along the Bay of Biscay and in the Bristol region of the English Channel (Bornarel et al. 2017). It is therefore relevant to understand how this 'CR' determination was arrived at. The European eel, as with most freshwater eels, is considered to form one randomly mating panmictic population across its entire, very large distribution area (Enbody et al. 2021; McCleave et al. 2016); this factor, compounded with its complex yet poorly understood life history traits and characteristics, make eel particularly challenging to assess within the standardized framework of the IUCN Red List criteria. It is insightful to note that the current IUCN assessment states: "*Indeed, for all intents and purposes it is assumed that practically nothing is known about the population dynamics of the oceanic phase of A. anguilla,"* (Pike et al. 2020a). In light of this state of knowledge, and since the IUCN assessment methodology addresses population in the context of historic numbers, this CR ranking has primarily been informed by the exceptionally rapid downward trend in abundance that has been identified in the stock, which has declined by 80-90% over three generations (ICES 2020a; ICES 2020b) - a duration of around 39 years (Pike et al. 2020a).

To put this decline into perspective, in historic times *A. anguilla* was super abundant and accounted for a major part of the fish biomass in freshwater systems across Europe (WWF

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[39] http://www.fao.org/iuu-fishing/en/
[40] https://cites.org/eng/disc/how.php
[41] International Union for the Conservation of Nature and Natural Resources (IUCN) website - https://www.iucnredlist.org
[42] https://www.zsl.org/conservation/species/fish-and-invertebrates/eel-conservation/iucn-anguillid-eel-specialist-group

2021). However, nowadays eel appear to have virtually disappeared from up-river areas in central Europe, even though historic data indicate that they previously thrived in such locations. Thus, loss of access to habitats - not only habitat loss itself - may well have contributed to the significant numerical decline of the stock. Experts therefore advise that the only way to address this decline is by protecting the stock across its entire range, since we do not know which part may be critical and which may not (ICES. 2021; ICES 2015).

Management of temperate eel stocks in their respective continental ranges

<u>European eel: How it is managed and its use in East Asian aquaculture</u>

Historically, although farms in East Asia were initially adequately supplied by locally wild-caught Japanese glass eels, by the 1990s declines in the recruitment of these native stocks had become so pronounced that farmers turned to European stocks to augment their requirements (UNODC 2020; Shiraishi & Crook 2015; UNEP-WCMC 2015). With a greater distribution area than the Japanese eel (Dekker 2003), the relatively greater abundance of *A. anguilla* glass eels at this time, in comparison to *A. japonica,* made this species a cheaper (albeit less desirable) substitute for farmers in East Asia (Pike et al. 2020a). However, the development of this new trade added further pressure onto an already depleted European eel stock, the decline of which had first been quantitively described in 1985 (Dekker 2003).

Although eel population dynamics are still not well-understood, scientists have identified that a multi-decadal decline of the European eel stock has been ongoing since the 1950s. Recent calculations indicate that glass eel recruitment has consistently declined by around 15% a year since 1980 – such that the current European eel stock is just 1-10% of what it once was (ICES 2020a; ICES 2020b; Dekker 2018). A suite of primarily anthropogenic impacts, such as pollution, barriers to migration (especially hydropower) and associated habitat loss, as well as unsustainable exploitation and trade - in addition to other impacts, such as climate change related effects, predation, disease and parasitism - have also brought about similar declines in Japanese and American eel stocks (SSC 2021). The declining trends of all three species are displayed together in Figure 11.

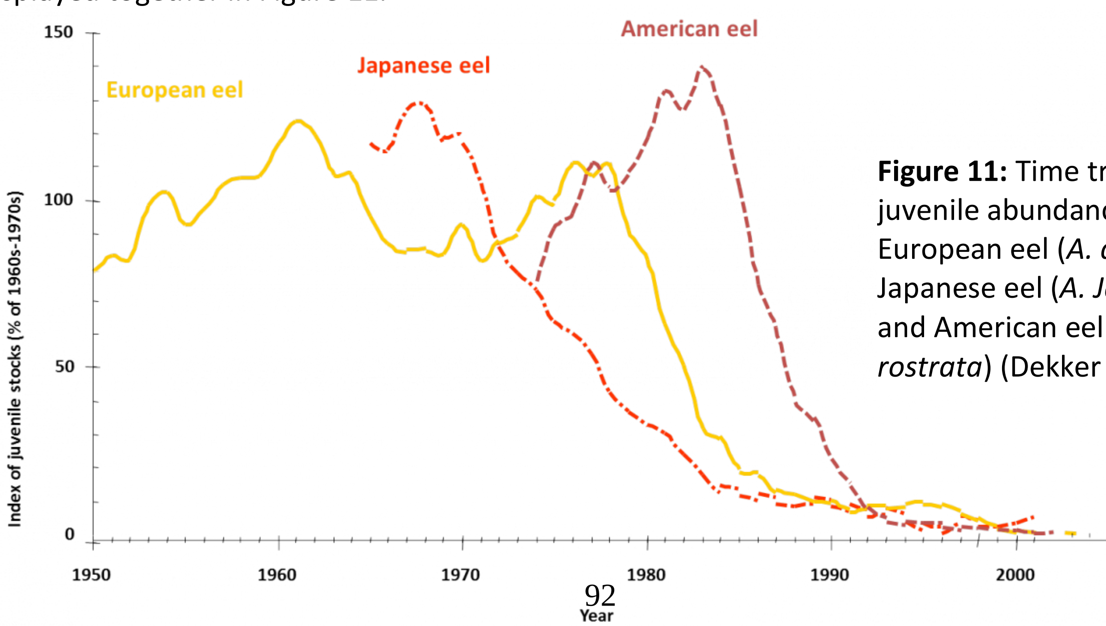

Figure 11: Time trends in juvenile abundance for the European eel (*A. anguilla*), Japanese eel (*A. Japonica*) and American eel (*A. rostrata*) (Dekker 2004)

Trends in glass eel recruitment for the European eel (A. anguilla), Japanese eel (A. japonica) and American eel (A. rostrata) (from Dekker 2004).

While excessive fishing pressure has evidently been a contributory factor, barriers to eel migration – including the historic introduction of water mills, through to present day dams and hydropower facilities – have evidently contributed to this downward trajectory, as have a range of other factors (Dekker 2018). Although lacking in robust quantitative data, historic publications indicate that declines in European eel abundance were already being observed by the 1800s; also of note is that accounts from different areas refer to eel being larger and present much further upstream than they are today (pers. comm. Willem Dekker, Ph.D., Senior Scientist, Swedish University of Agricultural Sciences, March 2021; SEG 2020; Dekker & Beaulaton 2016a).

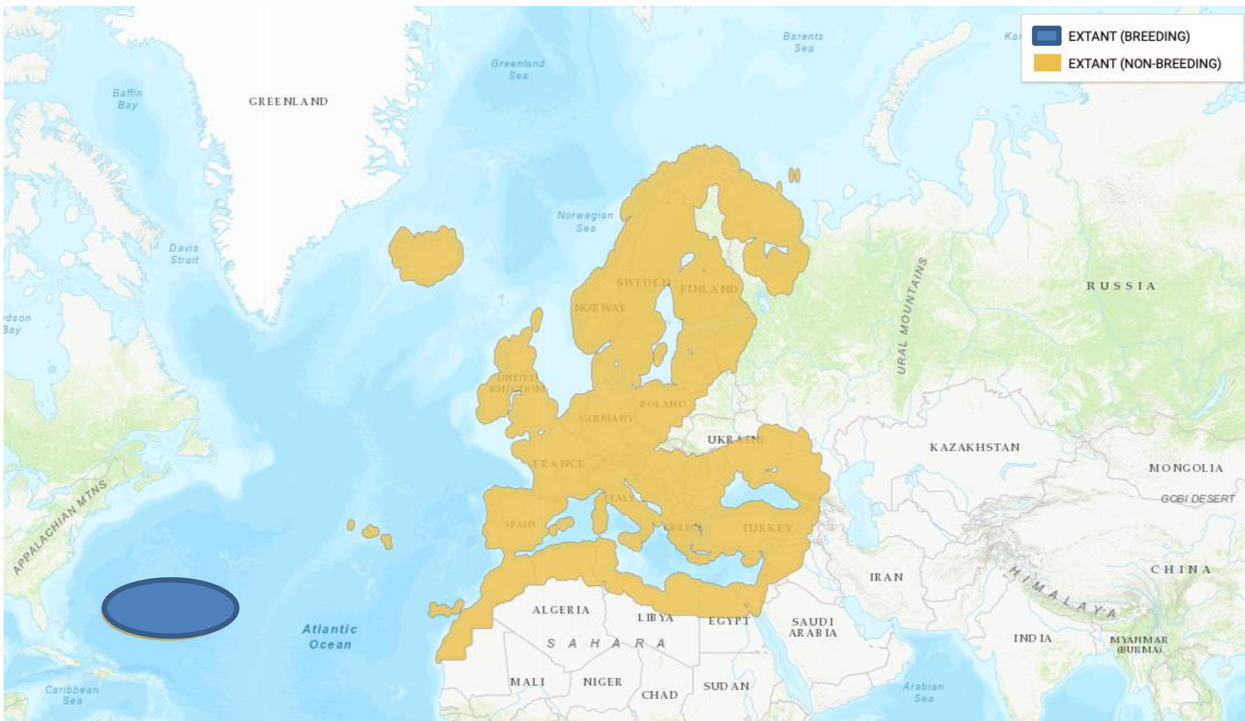

Figure 12: Map of the geographic range of the European eel (*Anguilla Anguilla*) – Source: The IUCN Red List of Threatened Species (Pike et al. 2020a)

Guided by the advice of scientists from the International Council for the Exploration of the Sea (ICES), in 2007 the European Union (EU) adopted a protection and recovery plan entitled, '*Council Regulation (EC) No 1100/2007 of 18 September 2007 establishing measures for the recovery of the stock of European eel*',[43] more commonly referred to as 'the Eel Regulation'. The overarching intent of this initiative is to ensure the protection and sustainable use of *A. anguilla* stocks and to recover their abundance to 40% of the natural, pristine stock. Importantly, the Eel Regulation also identifies how this goal can be achieved: by reducing anthropogenic mortality to a level that will allow this recovery to occur. In order to implement the Eel Regulation, EU Member States were required to develop and deploy Eel Management Plans (EMPs) for each of

[43] https://op.europa.eu/en/publication-detail/-/publication/a0d3c239-8086-4368-ae87-4eb3d1a477f5/language-en

their respective territories. Earlier in the same year, *A. anguilla* was also listed[44] in Appendix II of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES), and the listing subsequently came into full effect in March 2009 (Musing et al. 2018). While the jurisdiction of the Eel Regulation encompasses all *A. anguilla* stocks inside the EU, it naturally does not afford protection to those areas of eel recruitment beyond EU borders. The Appendix II listing, however, pertains to all CITES Parties[45], inclusive of those countries out with the EU that are part of *A. anguilla*'s continental range, which includes small areas of North Africa (Morocco, Algeria, Tunisia, Egypt) and the Middle East (Israel, Palestine, Lebanon, Syria, Turkey) (Nijman 2017). The full geographic range of *A. anguilla* is shown in Figure 12.

It should be noted that the CITES Appendix II listing does not ban trade in *A. anguilla*, per se, but specifies that an export permit must be sought from the relevant nation's authorities. Approval of such a permit is contingent upon an assessment of the sustainability and legality of such trade: sustainability is assessed via a 'Non-Detriment Finding'[46] (NDF) whereas the legality of such a proposed movement is determined by a 'legal acquisition finding'[47]. In the event that any approved trade movement should occur, it must in turn be reported in detail by the CITES Party that authorized it (Musing et al. 2018). In consideration of these requirements, in 2010 the EU's Scientific Review Group (SRG) decided to implement a zero import/export policy to prohibit European eel movements in and out of the region as it was determined that it was not possible to ensure that such trade would not be detrimental to the eel stock (UNODC 2020; Fletcher 2018; Shiraishi & Crook 2015). In other words, at present any trade of European eel into or out of the EU is indubitably illegal.

The above notwithstanding, internal trade, consumption and farming of European eel within the EU is still permitted to a limited degree - indeed, in compliance with the requirements of the Eel Regulation, movements of glass eel within the EU have been ongoing since 2013, in order to facilitate restocking of depleted eel river basins as part of each Member State's Eel Management Plan[48]. The area with the highest annual recruitment of *A. anguilla* glass eels is the Bay of Biscay, which accounts for around three quarters of the total (ICES 2007). In addition to France and Spain, the other principle glass eel fisheries in Europe are located in Portugal and the UK (UNODC 2020; Bornarel et al. 2017; ICES 2016). Interestingly, while the UK has hitherto been instrumental in providing juveniles to stock Lough Neagh in Northern Ireland as well as elsewhere in Continental Europe, this trade has now ceased due to Brexit[49, 50]; although the UK has made three attempts to file an NDF to facilitate continuation of this trade, in each instance these applications have been rejected by the EU's SRG thus, at the time of writing, the UK elver fishery has effectively lost its market (pers. comm. Andrew Kerr, Chairman of the Sustainable

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[44] https://cites.org/sites/default/files/eng/cop/14/prop/E14-P18.pdf
[45] https://cites.org/eng/disc/parties/index.php
[46] https://cites.org/sites/default/files/document/E-Res-16-07-R17_0.pdf
[47] https://cites.org/sites/default/files/document/E-Res-18-07.pdf
[48] The Eel Regulation requires that: "*By 31 July 2013, 60 % of eels less than 12 cm in length caught annually should be reserved for restocking*."
[49] https://www.bbc.co.uk/news/uk-northern-ireland-55818519
[50] https://www.business-live.co.uk/ports-logistics/brexit-gloucestershire-eel-farm-warns-19315763

Eel Group, March 2021). This abrupt loss of a legal market for one of the region's main glass eel fisheries has prompted concerns that the situation may encourage trafficking (Stein & Nijman 2021).

Prior to the EU's banning of *A. anguilla* trade, exports of European glass eels into East Asia had come almost exclusively from the EU (Nijman 2017), predominantly from France and Spain (Musing et al. 2018). Up until this time, European eel range states outside of the EU, which also had glass eel fisheries, had typically traded their eel products into the EU – and some of these were subsequently transhipped from the EU onward to East Asia (Nijman 2017). However, as a result of the impending ban, some non-EU European eel range countries started exporting into East Asia themselves. The most prominent of these was Morocco, which first sent glass eels to East Asia in 2009 (Nijman 2017), however, Morocco itself imposed a specific ban on the export of glass eels in 2013 (Musing et al. 2018). Algeria and Tunisia have also traded European eels into East Asia since the enaction of the Eel Regulation and the CITES Appendix II listing. A few other *A. anguilla* range countries have also been identified as glass eel exporters in trade data, although these latter quantities are describes as being comparatively 'insignificant' (Nijman 2017).

According to a recent 2018 study, which sought to evaluate the impact and implementation of the CITES Appendix II listing, while NDFs have been made by Algeria, Morocco, Tunisia and Turkey, in all instances the export of glass eels is explicitly banned by these countries (Musing et al. 2018; UNEP-WCMC 2018) – thus, in theory, it should not have been possible for any trade flow of European glass eels into East Asia to have taken place in recent years, even though other size classes of *A. anguilla* may have been approved for export. This situation, however, like much of the eel value chain, is far from straightforward and this theory does not align with customs trade data (Musing et al. 2018).

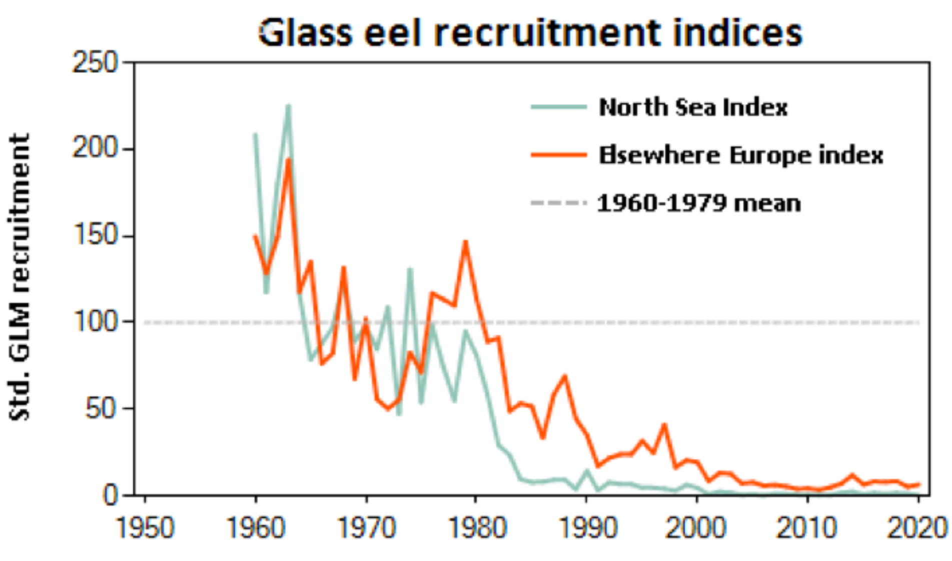


Figure 13: Trends in the abundance of young eel arriving at the European continent (ICES 2020b)

Despite the considerable confusion inherent in deciphering eel trade data, the management measures and protections that have been put in place to promote the recovery of the European eel may have realized some small measure of success. Figure 13 shows the recruitment indices of the glass eel stage of *A. anguilla* between 1960 and 2020; the sharp decline between the 1980s and 2011 is evident, followed by a very slight increase in recruitment during the last few years, particularly in 2014. However, the status of the European eel stock remains critical and whether this uptick in recruitment will continue remains to be see. As such, *A. anguilla* continues to be listed in CITES Appendix II (i.e., "*Species that are not necessarily now threatened with extinction, but that may become so unless trade is closely controlled*") (ICES 2019). It should also be noted that, in 2014, the European eel was listed under Appendix II of the Convention for Migratory Species of Wild Animals (CMS) (also known as the Bonn Convention), a treaty that provides an international governance framework for migratory species, with the aim of conserving such species throughout their respective ranges (Chambers et al. 2016b).

Japanese eel: How it is managed and its use in East Asian aquaculture

The questionable provenance and legality of glass eels used to stock East Asian eel farms is not limited to those that are sourced from Europe and North America, since domestically sourced Japanese eel is also subject to the pressures of poaching and illicit trade. Japan, traditionally the dominant consumer of eel in East Asia, started to farm *A. japonica* on a commercial scale around 1890–1900. By 1964, Japanese farmers had started to import *A. japonica* juveniles from neighboring countries, Taiwan, South Korea and mainland China. In 1969, Japan also started to work experimentally with *A. anguilla* using juveniles imported from France (Egusa 1979).

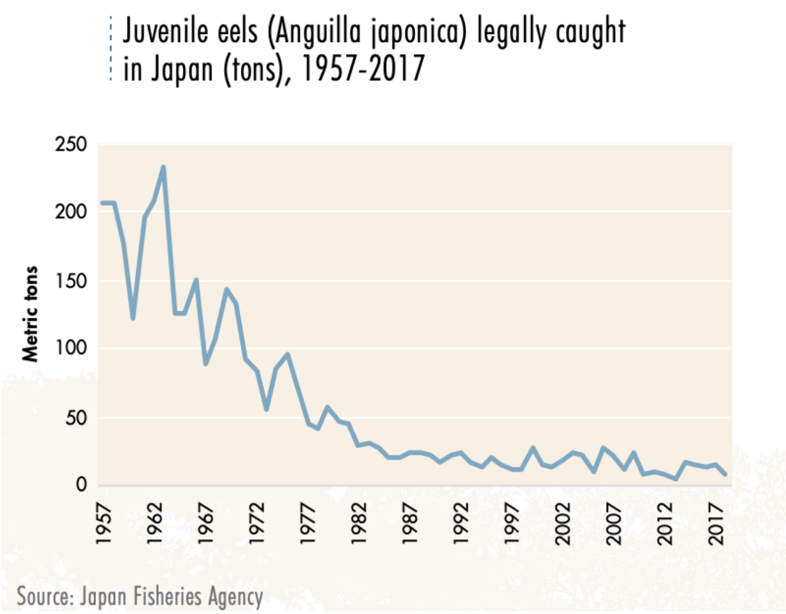


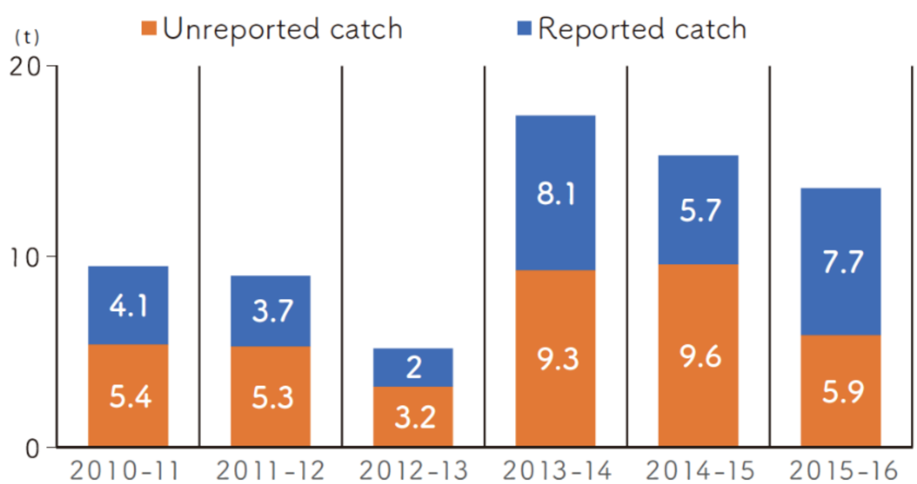
Figure 14: Legally sourced Japanese eel juveniles, 1957 to 2017 (UNODC 2020)

Although some indicators of a decline in the Japanese eel population started to become apparent in the 1970s, it was not until the 1990s, when *A. japonica* glass eel harvests plummeted for a number of successive years, that the issue became more widely acknowledged. This situation also prompted farmers to source larger quantities of glass eels from Europe, in order to keep their farms supplied with juveniles (UNODC 2020; Ringuet et al. 2002).

As with declines in anguillid populations elsewhere, a complex array of factors appear to have contributed to the decline of *A. japonica.* In addition to overexploitation, habitat destruction and deterioration has evidently had a significant impact on the abundance of Japanese eel stocks, particularly as a result of rapid economic development across the East Asian region in recent decades. For example, one study that utilized satellite imagery to examine 16 rivers across the four East Asian eel farming nations found that, on average, 76.8% of the effective habitat area for *A. japonica* had been lost in these environments between the 1970s and 2010. The greatest habitat loss was evident in Taiwan and China (49.3% and 81.5%, respectively), with a decline of 90.9% observed in the Yangtze River alone (Chen et al. 2014).

Literature indicates that China and Japan typically account for around 80% of the glass eel catches in East Asia, while Taiwan and South Korea catch the balance of ~20% (Shuo-zeng 2014). While the quality and quantity of data pertaining to *A. japonica* is somewhat variable across its geographic range, the most comprehensive data sets are available from Japan (Pike et al. 2020b). Based on inland eel catch data compiled by Japan's Ministry of Agriculture, Forest and Fisheries (MAFF), in 2013 the Japanese eel was assessed as 'endangered' and placed on the Japanese Red List [51, 52] (Pike et al. 2020b). It was also recently assessed as 'critically endangered' in Taiwan (Gollock et al. 2018). Eel experts comment that unreported and illegal fishing has occurred in Japan since the 1960s. Some estimates suggest that only around half of the glass eel catches are reported accurately, thus the balance of these may have been sourced from unlicensed fishers and/or have been sold via the black market (Kaifu et al. 2019; Shiraishi & Crook 2015). In Figure 14, the downward trend in legally caught *A. japonica* juveniles in Japan, between 1957 and 2017, is clearly evident [53], whereas Figure 15 shows the proportion of documented versus undocumented glass eels that were caught in Japan between 2010 and 2016. Note that around two-thirds of the 2014-2015 season is comprised of unreported catch.

Figure 15: (Right) Japan's annual catch of glass eels from 2010-2016, showing reported versus unreported amounts (MT) – Data sourced from the Fisheries Agency of Japan (JWCS 2017)



[51] https://www.japantimes.co.jp/life/2013/02/02/environment/ministry-officially-classifies-japanese-eel-as-species-at-risk-of-extinction/
[52] http://global.chuo-u.ac.jp/english/features/2017/08/9518/
[53] Note that eel farmers in Japan started to use glass eels (about 0.2 g) for aquaculture in the 1970s, whereas prior to the 1960s small yellow eels (5-20g) had been used. This means that the individual body size of 'juveniles', as depicted in Figure 14, was larger in the 1950s and 1960s than in the 1970s (pers. comm. Kenzo Kaifu, Ph.D., Professor, Faculty of Law, Chuo University, Director Eel Conservation Research Unit, August 2021).

Figure 16: The oceanic cycle of *A. japonica* in East Asia (AJASEA 2016)

By 2014, East Asian Japanese glass eel catches were estimated to be just ~5% of what they had been in the 1960s (Tsukamoto & Kuroki 2014). In acknowledgement of this precipitous decline, the four principle East Asian eel farming nations prepared and adopted a 'Joint Statement of the Bureau of Fisheries of People's Republic of China, the Fisheries Agency of Japan, the Ministry of Oceans and Fisheries of the Republic of Korea and the Fisheries Agency of Chinese Taipei on International Cooperation for Conservation and Management of Japanese Eel Stock and Other Relevant Eel Species' which is more commonly referred to as the 'Joint Statement' (MAFF 2014). This document sets out collaborative conservation and management measures agreed to by all participating nations, with the aim of mitigating the decline of Japanese eel stocks and other impacted eel species by restricting the amount of wild-caught glass eels used in aquaculture production (Pike et al. 2020b; AJASEA 2016; Shiraishi & Crook 2015). Since the advent of the Joint Statement, Japan and China now require both eel farmers and glass eel catchers to be licensed, whereas in South Korea there are specific months when glass eel fishing is banned and in Taiwan there are times when it is prohibited to export juveniles (Gollock et al. 2018). Since its inception in 2014, a number of press releases pertaining to the progress of this 'informal consultation' have been issued in response to CITES Notifications[54]. However, in more recent press release statements, it is notable that input from China is lacking, which suggests that China has not engaged in this process for several years (MAFF 2020; CITES 2018d).

Despite this collaborative initiative, however, these measures have not resulted in any decline in consumption of Japanese eel, since the agreed maximum 'ceiling' on juvenile inputs itself is estimated to exceed the actual glass eel catch by around 1.6 - 2.1 times (Kaifu 2019; Okamoto 2016). As shown in Figure 15, much of the glass eel catch in Japan - which has the most comprehensive data sets of all four East Asian eel farming nations – is unreported, thus there are inherent problems in using officially reported catch data to determine quotas since the glass eel input data referenced includes both legal and illegal catches. The first, and to date the only, scientific paper to assess the Japanese eel stock, using data obtained in Japan, was published in 2014; this study, which relied predominantly on official fishery catch statistics as well as catch per unit effort (CPUE) data in its abundance calculations, determined that "*The*

[54] https://cites.org/eng/taxonomy/term/42080

estimated stock size has recovered since 1990," (Tanaka 2014). Kaifu (2019) questioned this determination, however: a particular concern raised is that the data sets used in this 2014 assessment contained a statistical bias due to the stocking (i.e., translocation) of eels that takes place in many inland waters. Of note, in some areas almost 100% of the eels present are estimated to be stocked rather than naturally recruited individuals (Kaifu et al. 2018). This is further compounded with the aforementioned undocumented glass eels catches, which can arise for a number of reasons including, for example, when non-approved traders incentivize fishermen with a higher price than that offered by designated traders (Kaifu 2019). To remove the statistical bias of eel stocking in inland waters from abundance calculations, a recent study of Japanese eel in Japan elected to look instead at data sets from estuarine and coastal environments, where eel had not been stocked. This study, which considered data from 2003 to 2018, determined that there was a declining trend in eel stocks present in Japanese coastal and estuarine waters (Kaifu & Yokouchi 2019). It is also worth noting here that the Tanaka (2014) stock assessment is also contrary to the IUCN listing for Japanese eel, which classifies this species as endangered with a declining population trend (Pike et al. 2020b). However, this IUCN determination, which has been arrived at in consideration of a declining population trend observed over the last three generations, is based on a different methodology and different criteria, thus it is inappropriate to compare these determinations like for like.

The current IUCN listing for *A. japonica* notes that, in consideration of all available data on the multiple life-history stages of the Japanese eel, it is estimated that a population decline of at least 50% has occurred over the last three generations (24 years). The IUCN entry also comments that, in addition to stocking bias and large quantities of unreported catch, the ongoing occurrence of IUU fishing and the illegal trading of glass eels make it especially challenging to formulate an accurate evaluation of the Japanese eel stock (Pike et al. 2020b; Gollock et al. 2018).

Although the *A. japonica* stock status has evidently been more robustly informed by Japanese data, since out of all four East Asian eel farming nations it has the most extensive data sets, it is important to keep in mind that China is by far the largest volume producer.

Figure 17: The principal (dark grey) and other (light grey) eel farming provinces in mainland China – Data Source: TRAFFIC Report, based on Bureau of Fisheries, Ministry of Agriculture of China (2014) (Shiraishi & Crook 2015)

Since the mid-1990s, China has doubled its eel production, to the extent that it now accounts for 88% of East Asian farmed eel output, per FAO data (FAO 2021). Figure 17 shows the principal eel producing provinces of China; as can be noted, these are located in the south and southwestern regions, particularly in Guangdong and Fujian, which accounted for 87% of Chinese production between 2011 and 2017, according to Chinese production data (Stein et al. 2021).

American eel: How it is managed and its use in East Asian aquaculture

FAO fisheries data show that both the US and Canada have had small commercial American eel fisheries in place since the 1950s, however, the life stages that have been caught are not specified. Additionally, these data also document intermittent small volume eel catches reported by the Dominican Republic and Mexico since the mid-1990s (FAO 2021). Of note, since the 1950s, eels landed in the US and Canada have primarily been exported rather than consumed domestically, and the principal markets for these exports have been Asia and Europe (Jacoby et al. 2017). Interestingly, the only 'live eel' exports to East Asia that are documented in NOAA Foreign Fishery Trade Data took place in the 1980s (NOAA 2021).

While no indication of eel life-stage is provided in FAO capture fisheries data, the Atlantic States Marine Fisheries Commission (ASMFC), which is the agency responsible for monitoring and assessing the American eel stock in US territorial seas and inland waters along the Atlantic coast from Florida to Maine, notes that the US' glass eel fishery developed in the early 1970s, and that the initial impetus for this was to provide juveniles to eel farms in Japan (ASMFC 2012). Between 1972 and 1977, glass eel demand from East Asia heightened, and then tapered off for a time before strengthening again in the 1990s (Jacoby et al. 2017). The ASMFC website states that international demand for *A. rostrata* glass eels became particularly strong in 2011, further noting that this subsequently drove up the value and volume of landings (ASMFC 2020). This observation aligns well with inbound East Asian trade data, which shows an increase in *A. rostrata* glass eel imports concurrent with a decline in *A. anguilla* - pursuant to implementation of the EU's trade ban in 2010 (see Figure 19). Of additional note, the value of the glass eel fishery in the US State of Maine surged from an annual value of a few million dollars to over US$40 million around this time (UNODC 2020), as described in the updated introduction to this report (see Figure 4). This surge in value also prompted the so-called 'eel gold rush', giving rise to intense poaching activity all along the Atlantic seaboard (Morrison 2020; Chambers et al. 2016b; Miller & Casselman 2014).

To put this into historic context, by 2006 Maine had become the US' only remaining sizeable commercial glass eel fishery; although a few permits are still held by elver fishers in South Carolina, these catches constitute a very small proportion of total authorized glass eel landings in the US and are restricted to just one river (Kaifu et al. 2019). Elsewhere in the US, glass eel collection is now prohibited (Shepard 2015), even though glass eel fisheries had originally also sprung up all along the coastal states, from Florida to Maine, in the latter part of the last century (Kaifu et al. 2019). In the 1990s, before any legal provisions had been deemed necessary, elver fishermen could legally 'chase' the eel run all the way up the coast during the recruitment season, first starting in Florida in January and then working up the coast to Maine in March (Ebersole 2017), where the season continues through until June (Chase 2018). In 1989, Canada also developed glass eel fisheries in the Maritimes Region, which still continue today in Nova Scotia and New Brunswick (DFO 2018; Shepard 2015; Chaput et al. 2014). Elvers arrive in Scotia-Fundy waters in late March and early April, with the peak season occurring in May. In the Maritimes, a total of nine licences are held: eight commercial licences and one communal commercial licence, each of which permits the holder to engage a specified number of fishers under it (DFO 2018).

Historically, in terms of biomass the American eel was once North America's most abundant fish and occupied all watersheds east of the continental divide (Kaifu et al. 2019). Like the European eel, which used to be super abundant across its range, and the Japanese eel, a decline in the American eel population started to become increasingly evident to scientists in the 1970s and 1980s (Drouineau et al. 2018; DFO 2018; Miller et al. 2016). In this regard, it is interesting to reflect on the comments of Miller et al. (2016) who note that, "*Despite uncertainty in linking the declines of the recruitment of northern hemisphere anguillid eels to any one specific cause, it seems possible that a variety of factors came together at about the same time to cause the drastic declines that were observed*."

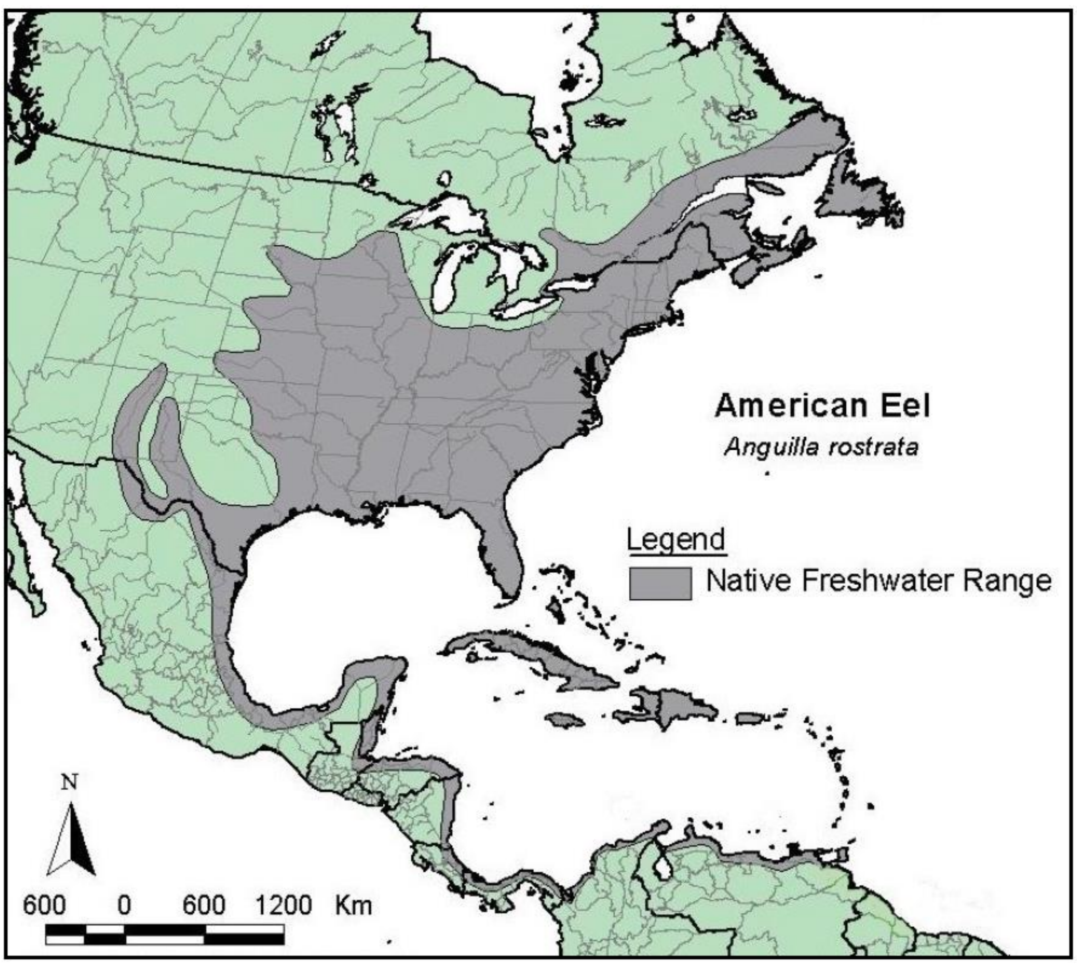


Figure 18: Freshwater range of *Anguilla rostrata* in the Americas (Shepard 2015)

The IUCN *A. rostrata* listing notes that: "*The species was once extremely abundant in watersheds and tributaries in two of the largest reservoirs for the species - Lake Ontario and St. Lawrence River system and Mississippi River system - but has gradually declined since the turn of the 20th century, most rapidly from the 1970s to the present*," (Jacoby et al. 2017). Since most of the research conducted on *A. rostrata* thus far has focused primarily on the US and Canada, much less is known about its more southerly range, both in terms of current and historical distribution. Recent field research has confirmed that the American eel is widely distributed across the Wider Caribbean Region, extending to the northern part of South America, including eastern Venezuela and the island of Trinidad. Researchers also note that those detrimental impacts that have decreased the species' northerly range and abundance have likely affected the American eel similarly across its southerly range (Gollock et al. 2018; Benchetrit & McCleave 2016). Data pertaining to the American eel stock in these southerly regions is scant however (Jessop & Lee 2016), although it is known that some nations within the southerly continental range of *A. rostrata* have also developed their own glass eel fisheries, which supply eel farms in East Asia. These are located in the Dominican Republic, Haiti, Cuba and, more recently, in Jamaica (SSC 2021; Gollock et al. 2018).

In order to support the management of *A. rostrata* in the US, ASMFC prepared an American Eel Benchmark Stock Assessment in 2012 (ASMFC 2012), which was later updated in 2017 (ASMFC 2017): in both instances, since total landings were considered to be low but stable, no determination that overfishing was occurring was made during these assessments, however, it was determined that the American eel stock was depleted and that it was at or close to historically low levels (ASMFC 2020). As with investigations into other declining anguillid populations, a myriad of factors have been identified as potential contributory causes, including habitat loss, barriers to migration, turbines, pollution, parasites, changes in the Sargasso Sea, climate change, as well as overexploitation (Walker 2019; Shepard, 2015). While such factors are challenging to quantify, in terms of habitat loss, it is relevant to note that literature states that the historic length of streams accessible to eels in the US has declined by as much as 84%, especially between Maine and Connecticut (Jacoby et al. 2017; Jessop & Lee 2016; Miller et al. 2016).

In 2014, the IUCN deemed that it was appropriate to assign an 'endangered' listing to the American eel, in light of its ongoing declining population trend and the continuation of threats to its survival. When the report underpinning the listing was subsequently updated in 2017, the endangered status for the American eel was retained, with the authors further commenting that present data indicates that the species has been experiencing ongoing declines in population, recruitment and escapement for the last three generations, a period of around 36 years. Additionally, the listing states that "*Integrated management for this panmictic species is lacking*," (Jacoby et al. 2017). Another update to the IUCN American eel assessment is anticipated soon, although COVID-19 has evidently caused delays to this process[55].

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[55] https://www.fishsec.org/2020/08/26/european-eel-remains-critically-endangered-in-latest-iucn-red-list-assessment/

Although the IUCN's stock-wide assessment for the American eel ranks it as endangered, neither the US nor Canada have arrived at this determination using their own respective federal ranking mechanisms, which of course are based on different assessment methodologies and criteria. In the US, the act which is in place in this regard is the Endangered Species Act (ESA) of 1973[56] and the lead federal agencies that are designated to implement activities under this act are the US Fish and Wildlife Service[57] (USFWS) and the US National Oceanic and Atmospheric Administration (NOAA) Fisheries Service,[58] both of which play a role in management of the American eel due to its catadromous life history (Jessop & Lee 2016). In 2007, and again in 2015, USFWS reviewed the status of the American eel but on both occasions it was decided that Endangered Species Act (ESA) protection was not warranted[59].

Against a backdrop of concerns about declines in American eel abundance, such as those observed in the Lake Ontario and St. Lawrence River system (Norchi et al. 2016; ASMFC 2012), the first USFWS review in 2007 was requested by two brothers in Maine (Morrison 2020; Miller & Casselman 2014). At the end of the review period, USFWS released their evaluation entitled, 'Endangered and Threatened Wildlife and Plants; 12-Month Finding on a Petition To List the American Eel as Threatened or Endangered' (USFWS 2007), which stated that while the American eel has been extirpated from around 25% of its historic freshwater habitat during the last century - largely as a result of dam building - and even though the species' abundance has declined in some areas, the American eel is still widely distributed throughout around 75% of its historic range. The finding statement also concluded that, due to the panmictic nature of the American eel stock, it is not at risk of genetic loss, such as is associated with the decline of genetically distinct subpopulations and that, as a highly plastic species, it has the ability to adapt to a broad range of freshwater, estuarine and marine habitats, further noting that no threats to the American eel in marine habitats are known to exist. The final determination of the finding was that "*Listing of the American eel as threatened or endangered under the Act is not warranted."*

The second USFWS status review in 2015 was catalyzed by a petition from the Council for Endangered Species Act Reliability (CESAR)[60]. In order to assess any new information that had not been considered or available during the previous review, and to revisit the findings of the original assessment, new information was solicited from stakeholders and other interested parties and a peer-reviewed report (Shepard 2015) was prepared. However, the findings of this review remained unchanged from the 2007 determination: "*After a review of the best available scientific and commercial information, we find that listing the American eel is not warranted at this time. The best available scientific and commercial information indicates that the American eel remains widely distributed throughout its native range and remains relatively abundant*," and, "*Although listing is not warranted at this time, we ask the public to continue to submit to*

[56] https://www.epa.gov/laws-regulations/summary-endangered-species-act
[57] https://www.fws.gov
[58] https://www.fisheries.noaa.gov
[59] https://www.fws.gov/northeast/americaneel/
[60] https://www.seafoodsource.com/news/environment-sustainability/american-eel-still-not-endangered-association-argues

us any new information that becomes available concerning the status of, or threats, to the American eel," (USFWS 2015b).

In Canada, the entity tasked with assessing the status of wild species and determining if they are at risk of extinction is the Committee on the Status of Endangered Wildlife in Canada (COSEWIC), an advisory panel that was created in 1977 to provide guidance to the Minister of Environment and Climate Change[61]. After reviewing the status of the American eel in 2006 (COSEWIC 2006), COSEWIC designated it as a 'species of special concern', which they later upgraded to 'threatened' in 2012. This was deemed necessary due to general declines in abundance indices over a significant portion of its distribution, as well as dramatic declines particularly in Lake Ontario (>99%) and the Upper St. Lawrence River, during the last two or more generations (Jessop & Lee 2016; Norchi et al. 2016; Miller & Casselman 2014; Cairns et al. 2014; DFO 2014; Young & Koops 2014). Thus far, neither of these designations have been accepted by Canada's federal cabinet, which has yet to make a decision as to whether the American eel's status warrants protection under the Species at Risk Act (SARA) (Jessop & Lee 2016), a statute that was introduced in 2003 to enable the protection of endangered or threatened species and their habitats[62]. While pressure is mounting from environmental groups for the government to move ahead with its decision making process and to extend greater protection to eels[63] no deadline appears to have been set for this as yet[64]. The Government of Canada's 'Species at Risk Registry' currently includes the status on *A. rostrata* as "*Not on Schedule 1 (under consideration for addition)*"[65].

It should be noted that although the SARA outcome is as yet undecided, since 2008 the American eel has been afforded protection as an endangered species under Ontario's Endangered Species Act (ESA), in the jurisdiction of the province of Ontario. This designation "*Prohibits the killing, harming, harassing, possessing, buying, selling, trading, leasing or transporting of this species*,"[66, 67] (MacGregor et al. 2010; Chaput et al 2014).

While a SARA decision is still pending at the federal level, the government have initiated an information gathering process to inform this procedure, including, in 2013-2014, the preparation of a Recovery Potential Assessment (RPA) for the American eel which incorporates several publications (Cairns et al. 2014; Chaput et al. 2014; DFO 2014; Pratt et al. 2014; Young & Koops 2014). These reports, prepared by Fisheries and Oceans Canada[68] (DFO) review the current knowledge of habitat requirements, examine stock status threats and how they might be mitigated, appraise current trends in eel abundance indices and recovery target timeframes

[61] https://www.cosewic.ca/index.php/en-ca/
[62] https://www.canada.ca/en/environment-climate-change/services/environmental-enforcement/acts-regulations/about-species-at-risk-act.html
[63] https://cwf-fcf.org/en/explore/eels/?src=menu
[64] https://www.smithsonianmag.com/science-nature/eel-fortune-180968028/
[65] https://species-registry.canada.ca/index-en.html#/species/891-632
[66] https://www.dfo-mpo.gc.ca/species-especes/profiles-profils/eel-anguille-eng.html
[67] https://www.ontario.ca/page/american-eel
[68] https://www.dfo-mpo.gc.ca/index-eng.html

(i.e., short, one generation; medium, three generations; and long-term, >50 years), and additionally investigate the results of population modelling under various hypotheses and harm scenarios. These RPA authors also comment that monitoring and stock assessment efforts for *A. rostrata* would greatly benefit from increased co-ordination between all nations across the species' range, including the US and the Caribbean (DFO 2014).

This ambition for greater integrated management was also echoed in an ICES review that was published following the second International Eels Symposium, which was held during the American Fisheries Society (AFS) Annual Meeting in Québec City, in 2014. The review noted that conservation issues for anguillid species are international in scope, thus internationally-coordinated governance measures are required: "*In Europe, international integration of eel assessment, management, and protection is underway under the auspices of ICES, while in North America, Asia, and Oceania, only tentative steps have been taken so far. For non-European countries, management is typically only conducted at the regional scale; this is inadequate considering the panmictic nature of anguillids, which calls for inter-jurisdictional management*," (Castonguay & Durif 2016).

Shortly thereafter, in 2015, the "American Eel Symposium: Future Directions for Science, Law, and Policy" was held in Maine. The aim of this symposium was to bring together US and Canadian stakeholders to discuss the conservation and management of the American eel, alongside eel experts from Europe who were able to provide comparative perspectives and insights from their experiences with the European eel (Freestone et al. 2016). During the symposium, the challenge and importance of wider collaboration incorporating southern range states was also discussed (Chambers et al. 2016b).

The 'Eel Problem' of the new millennium: Eel trafficking

Although eel farming has been practiced in East Asia for some time, particularly in Japan, it is only within the last few decades that an international trade in glass eels has developed and become synonymous with the expanding sector. Concurrent with the growth of this new trade have been the growing concerns of eel scientists, in response to the dramatic population declines observed globally across all anguillid species (Righton et al. 2021). While the causative factors behind globally declining temperate eel stocks are yet to be clearly determined – and likely involve a broad suite of influences – the overexploitation of eel, at various life stages, is identified as one such factor (Pike et al. 2020a; Pike et al. 2020b; Jacoby et al. 2017). In many regions, anguillid conservation concerns have prompted the design and implementation of various governance mechanisms to control over-fishing, with authorities in many anguillid range countries placing limitations specifically on glass eel fisheries and exports, as discussed in some detail in the species specific sections above. As a result of these measures, the availability of legally-sourced glass eels has greatly diminished, causing a shortfall in fry supply to East Asian eel farms (Musing et al. 2018; CITES 2018b) – a situation that has given rise to the somewhat newly defined phenomenon of glass eel trafficking (Kaifu et al. 2019).

Due to the globally complex nature of the eel value chain, and the fact that legal and illegal glass eels are often transported alongside each other, it is a highly challenging trade network to analyze and comprehend. Trade data analysis from the last decade show that there have been substantial shifts in glass eel trade patterns, dependent upon the varying annual recruitment level of different species as well as the effectiveness of enforcement efforts in different jurisdictions (Gollock et al. 2018). Particularly influential on the disruption of trade flows during the last decade has been the EU's total ban on *A. anguilla* imports and exports, which was implemented in 2010 pursuant to the introduction of the Eel Regulation and the CITES Appendix II listing for *A. anguilla*, both of which were initiated in 2007, with the latter coming into full force in 2009 (Righton et al. 2021; Shiraishi 2020). Literature notes, however, that European eel continues to be imported, grown out in, and re-exported from farms in China even though legal sourcing of this species ended several years ago (Shiraishi & Crook 2015).

Deciphering data from the East Asian eel value chain

In 2015, a key report was produced by TRAFFIC [69], entitled 'Eel market dynamics: An analysis of Anguilla production, trade and consumption in East Asia,' (Shiraishi & Crook 2015). By utilizing an array of data sources and officially reported eel industry statistics, and cross-examining these values with one another, the authors of this report highlighted many significant data discrepancies across the different stages of the eel sector value chain – particularly with regard to the production and consumption quantities of cultured eel in China.

For example, in consideration of the volume of eels cultured in China between 2004 - 2013, FAO data indicate that production was within the range of 150,000 - 215,000 MT per annum, whereas according to other data sources, such as the Joint Statement, China's annual production values were considerably less, ranging between 15,000 - 125,000 MT per annum. Likewise, the FAO production volumes reported for China do not correlate well with the reported legal glass eel inputs (see Figures 24 and 25), which have evidently been considerably less in some years than in others, due to reduced availability. Given the dominance of China in the eel sector, the large statistical variations evident in different data sources make it exceptionally challenging to determine the actual production and consumption volumes of eel products in East Asia. Likewise, a direct analysis of Chinese eel production volumes in tandem with subsequently documented export volumes would suggest that China must have significantly increased its domestic consumption of eel product in recent years, if FAO data are correct. Some experts suggest that true production values may lie somewhere between those presented in the Joint Statement and those recorded by FAO (Shiraishi & Crook 2015).

This TRAFFIC analysis also shows that a substantial proportion of the eels farmed in East Asia, all of which are reported to FAO as *A. japonica* (FAO 2021), must actually be comprised of other anguillid species – a conclusion supported by the well-documented decline in Japanese glass eel availability, as well as the documented (and undocumented) rise in illegal trafficking of *A.*

[69] TRAFFIC is an organization that was established in 1976 by WWF and IUCN, which monitors wildlife trade to ensure that such trade does not present conservation concerns - https://www.traffic.org/news/traffic-iucn-and-wwf-renew-partnership/

anguilla[70] and *A. rostrata* glass eels[71, 72] (UNEP-WCMC 2015, Shiraishi & Crook 2015), in addition to substantial legitimate shipments of the latter. Furthermore, many records of glass eel imports into East Asia over the last decade have no corresponding records in exporter data and this trend is particularly evident in instances where the exporting country has an export ban in place (Shiraishi & Crook 2015). For example, since becoming CITES-listed, any movement of European eel, of any life stage, is required to be accompanied by a CITES certificate should such export/import take place outside of the species' continental range (UNODC 2020). In this regard, it is interesting to note that CITES trade data indicate that, between 2009 and 2013, Japan imported over 30,000 MT of *A. anguilla* 'meat' from China, which accounted for 98% of all *A. anguilla* meat imports reported to CITES per April 2015 (Shiraishi & Crook 2015).

Figure 19 shows aggregated glass eel trade data recently compiled by TRAFFIC, which shows all documented East Asian imports of live eel fry for farming between 2004 and 2019, as per East Asian customs data. This is displayed alongside the declining trend of locally sourced Japanese glass eel inputs, the species of preference for both consumers and farmers in East Asia (Shiraishi & Crook 2015).

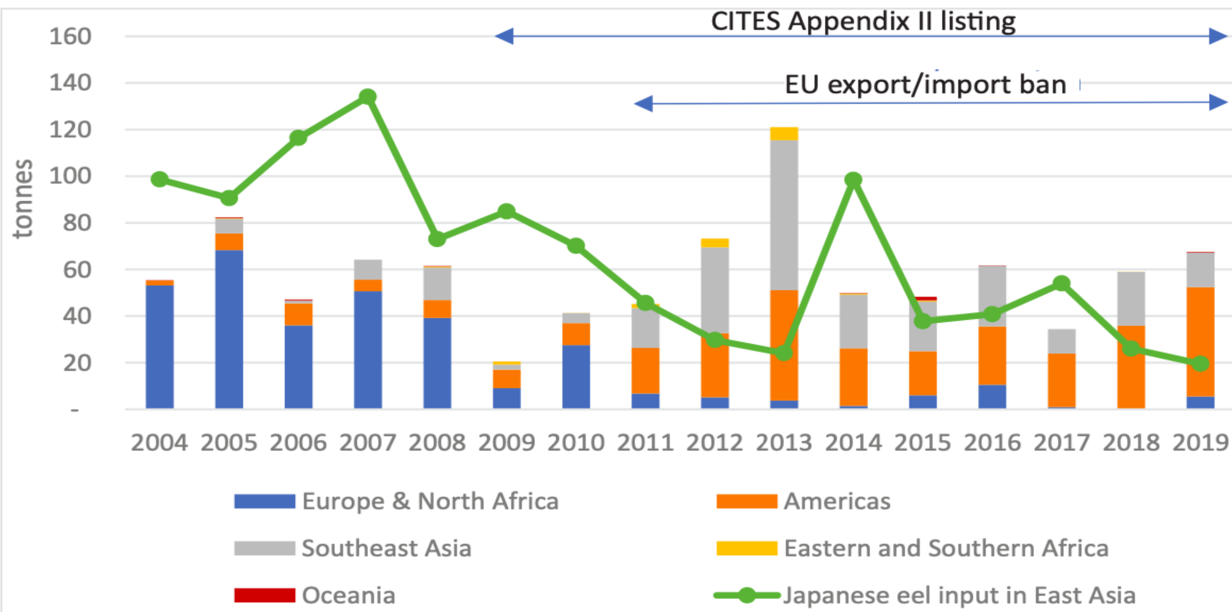

Figure 19: Imports (MT) of live eel fry for farming (all sizes) into East Asia (excluding trade between East Asian countries/territories) and the supply of *Anguilla japonica* for farming in East Asia, 2004–2019* (Shiraishi 2020)

*Europe and North Africa (likely to be *A. anguilla*); Americas (likely to be *A. rostrata*); Southeast Asia (likely to be *A. bicolor* and other tropical *Anguilla* species); East/Southern Africa (likely to be *A. mossambica* and other tropical species); Oceania (likely to be *A. australis*). Note: supply of *Anguilla anguilla* for farming in East Asia was reported by fishing season; however, data for the 2018-2019 fishing season is, for example, recorded in the figure for 2019;

[70] https://www.seafoodsource.com/news/supply-trade/seafood-salesman-convicted-of-smuggling-usd-68-million-of-eels-through-britain
[71] https://www.cnbc.com/2017/08/07/as-eels-grow-in-value-us-government-clamps-down-on-poaching.html
[72] https://www.justice.gov/opa/pr/two-men-indicted-illegally-trafficking-american-eels

supply of *Anguilla anguilla* for farming in East Asia in the 2013-2014 fishing season seems to have been overreported because of it being the base year to set input quota (Kaifu *et* al. 2019). *Sources: East Asian Customs; Anon. (2019a); Joint Press Releases of the East Asian eel meetings.*

Figure 20: Documented glass eel imports (all species) into China from 2001 to 2017 (UNODC 2020)

Another significant report that highlights discrepancies in the East Asian eel value chain is the United Nations Office on Drugs and Crime report, entitled 'World Wildlife Crime Report - Trafficking in Protected Species' (UNODC 2020). One observation included in this report, in consideration of reported Chinese eel production, is that documented glass eel inputs do not correlate well with reported output. As shown in Figure 20, pursuant to the CITES Appendix II listing of European eel in 2009, officially documented volumes of glass eel imports (all species) into China declined to around half of what they had been. Across a similar time span, Chinese export data indicate that between 2008 and 2016, China exported around half of its domestically-captured *A. japonica* glass eel to Japan, a factor that the UNODC authors use to extrapolate that around two-thirds of China's cultured eel production over this timeframe must have been reliant on imported glass eels – however, this evidently does not tally with glass eel importation records (UNODC 2020). Furthermore, this hypothesis does not correlate with the growth that the sector has evidently experienced during this time frame (see Figure 7 in the updated introduction for an overview of sector growth); note that 1 kg of European glass eels reportedly yields ~ 750 kg of filet (UNODC 2020).

When reported Chinese eel production volumes are considered in tandem with glass eel inputs, it is apparent that the efficiency of production would have had to have increased ten-fold between 2000 and 2015, for the stocking and end harvest numbers to align – i.e., 1 kg of glass eel initially yielded 1.5 MT in 2000 but by 2015 this had increased to ~15 MT; even in light of differing glass eel weights [73, 74] and improvements in transportation and husbandry methods, this 1000% increase in yield appears somewhat improbable. The authors conclude that: "*Stark changes between glass eel imports and production (taking into account utilization of*

[73] Note that *A. anguilla* glass eel comprise around 3,000 fish/kg (Dekker & Beaulaton 2016b), whereas 1 kg of *A. japonica* equates to ~ 5-6,000 individuals (Crook & Nakamura 2013), and northern range state *A. rostrata* elvers average 3,660 elvers/kg at the start of the fishery season to 5,580 elvers/kg at the end (Jessop 1998).

[74] Similarly, UNODC state that "*The China Eel Industrial Association reports that there were between 2,200 and 3,800 European glass eels per kilogram, making them the largest glass eel species imported. In contrast, there are between 5,500 and 6,000 Japanese eels per kilogram, and around 5,000 American eels per kilogram*," (UNODC).

domestically caught Anguilla japonica) suggest an undocumented source of glass eel supply. This supply need not be of European eel, but the fact that these ascribed imports of glass eels are not recorded raises suspicions about their origins," (UNODC 2020).

Law enforcement and its impact

European eel smuggling and the success of Operation Lake

Smuggling eels into East Asia continues to be the largest wildlife crime perpetrated in Europe (Dekker 2020), both in terms of the number of individual animals involved and the monetary value realised (NWCU 2019). As is apparent in Figure 19, since the implementation of the EU import/export ban and the CITES Appendix II listing, the documented trade flow of European eels going into East Asia has declined considerably, a trend which has surely been effectuated by an increase in law enforcement efforts (UNODC 2020). These interventions have revealed the presence of extensive smuggling networks and have provided insights into the true scale of trafficking taking place (Dekker 2020). As criminal networks have been exposed, so have the modus operandi of their operations and concealment methods, which include mis-declaration and the co-mingling of illegal eels amongst other legal commercial cargo goods, as well as transporting them on passenger planes in suitcases (UNODC 2020; Diggins 2020; CITES 2018b).

Along with other enforcement agencies across Europe, Europol launched Operation Lake in 2015. This transnational initiative, which aims to counteract wildlife trafficking, in addition to other environmental crimes and associated illicit activities, has made significant progress in combating the efforts of eel smuggling gangs and syndicates who are targeting the European eel (Europol 2017). Regular press releases from Europol provide updates on the progress of Operation Lake, including details of the volume of glass eels seized and the number of arrests made (Europol 2020; Europol 2019; Europol 2018a; Europol 2018b; Europol 2017).

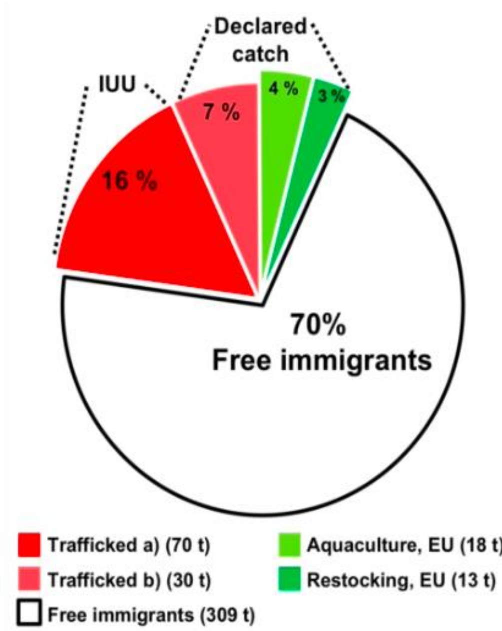

Figure 21: The entire chart represents the total annual ocean recruitment of migrating juvenile European eel throughout its European range (~ 440 MT). Each segment represents eels destined for different destinations: Restocking of EU waters; EU aquaculture; Trafficked IUU catch (a); and Trafficked 'legal' catch (b). The proportion of eels not caught are referred to as 'Free immigrants'. Credit: Sustainable Eel Group (Stein 2018)

In 2018, Europol estimated that 350 million European eels, weighing 100 MT, were being trafficked out of Europe each year to supply Chinese eel farms (Europol 2018a). When this estimate from Europol is considered in tandem with estimates of annual European eel recruitment throughout its European range, which models indicate is in the region of 440 MT (Bornarel et al. 2017), it can be extrapolated that approximately one quarter (23%) of all arriving eels were being caught and subsequently trafficked to eel farms in East Asia, as depicted in Figure 21. Since this time, international enforcement efforts have evidently had a significant degree of success in curtailing trafficking of *A. anguilla*, to the extent that the 2017/2018 period that the aforementioned Europol estimate pertains to is now referred to as 'peak season': after a period during which seizures and arrests kept increasing, both have subsequently declined somewhat (pers. comm., Florian Stein, Director of Scientific Operations, SEG, March 2021; Stein 2020). However, experts note the importance of continued surveillance and enforcement efforts (Diggins 2020), which are ongoing during 2021, as evidenced by recent arrests in Portugal (JN 2021), France, Spain and the UK. Europol estimate that in recent years the value of European eel smuggling has been in the region of €3 billion (US$3.65 billion) (Taylor 2021).

To further contextualize the scale of such trafficking, some experts have commented that the volume of *A. anguilla* glass eels seized in the decade following the CITES-listing for this species equated to around 10% of the total supply of glass eels utilized by the major East Asian producers during this time span. However, given that a great deal of trafficking naturally goes undetected, it is most challenging to calculate the entire extent of such illegal eel movements (UNODC 2020). This situation, compounded with the evident lack of traceability across the sector value chain and the inability to reliably verify eel inputs and outputs, especially in China, means that the full extent of illegal trade taking place is unknown.

The obligations of CITES Parties

An important factor to acknowledge in the success of these enforcement operations is the fact that, unlike other *Anguilla* species, *A. anguilla* is listed in CITES Appendix II, an important tool that makes it much simpler for law enforcement entities to identify the legality, or otherwise, of any trade movement involving this species. CITES obligations require that any proposed trade of an Appendix II listed species must be formally approved by the relevant authorities of the exporting country prior to export; such approval must attest that the proposed trade is both legal and sustainable, the first of which is affirmed by a legal acquisition and the latter by an NDF (Non-Detriment Finding). If these approvals are not appropriately determined, then the CITES Party in question is in violation of the Convention (Foster & Vincent 2021).

With regard to NDFs, should any concerning trade patterns emerge involving Appendix II listed species, then a Review of Significant Trade (RST)[75] is initiated, whereby a Party is requested to provide justification for the NDFs that they have issued and furnish this to the relevant CITES committee. If the committee finds the NDF determinations to be indefensible, then formal recommendations will be provided to the Party to assist with improved implementation of the Convention – and if such measures fail, then trade sanctions become a possibility (Foster & Vincent 2021).

[75] https://cites.org/eng/imp/sigtradereview

As a result of the aforementioned CITES obligations, the EU Scientific Review Group (SRG) determined that, given the critical conservation status of the European eel stock, it would not be possible to grant approval for any NDFs, therefore a total ban on the export and import of this species was implemented in December 2010 [76]. In consideration of this decree, provision was made for those farms in East Asia that were already in the process of raising *A. anguilla* which had been legally procured as juveniles prior to the ban; to facilitate this transition period, re-export permits for *A. anguilla* were approved for use in China up until June 2015 (Shiraishi & Crook 2015). Since this time, however, it has been illegal to import *A. anguilla* into the EU (Musing et al. 2018). Since making their original determination, the EU SRG have reconvened each year to reappraise the situation and, thus far, the zero-import/export quota has remained in place [77].

Although the EU blanket trade ban naturally does not encompass non-EU *A. anguilla* range states, these nations are all CITES Parties, thus in these jurisdictions, strong regulations and catch quotas were also put in place to comply with CITES obligations (Stein et al. 2021). While NDFs have been made in the interim by Algeria, Morocco, Tunisia and Turkey, the information presented by these range states, either in the form of Notification responses or through the CITES Review of Significant Trade (RST) process, indicates that the export of glass eels is not permitted by the authorities in these countries (Musing et al. 2018; UNEP-WCMC 2018) even though other larger forms of *A. anguilla* may be approved for export (e.g., Morocco specifically states that export of glass eels <10 cm is illegal) [78]. Furthermore, according to information submitted to CITES as part of the RST process, glass eel exports would appear to be prohibited in most range states (CITES 2018b). Thus, in theory, it should not have been possible for any meaningful trade flow of European glass eels into East Asia to have taken place in recent years – although evidently this has not been the case and trafficking is an ongoing concern (Stein et al. 2021; Knott 2021; Richards et al. 2020; Stein et al. 2016).

Development and implementation of DNA diagnostic tools

Numerous reports and studies, which have analyzed and compared various sources of customs and trade data across the eel value chain, concur that a large proportion of ongoing trade is in violation of national and international laws (Pavitt et al. 2021; Stein et al. 2021; UNODC 2020; Musing et al. 2018). However, this can be challenging to prove in a court of law, particularly for American and Japanese eels, for which there are both legal and illegal trade flows entering, and within, East Asia. Furthermore, while the CITES Appendix II listing makes it easier to determine if a trade movement involving European eel is legal or not, it is not easy to visually differentiate between anguillid species, since European, Japanese and American eels are all morphologically extremely similar (CITES 2018b).

[76] https://publications.jrc.ec.europa.eu/repository/handle/JRC92953
[77] https://circabc.europa.eu/sd/a/a30daa66-704d-4160-a7fe-81948f22944b/92_summary_SRG.pdf
[78] Note that while each CITES permit is not publicly available, trade data can be downloaded from CITES trade database (https://trade.cites.org).

At present, DNA barcoding is deemed to be the most effective way of identifying one species from another, a procedure that is both time consuming and expensive (Pinchin 2021; CITES 2018a; CITES 2018b). A recent study in Hong Kong, which used DNA barcoding to ascertain the species of eel present in supermarket products, found that 45% of the items sampled contained European eel (Knott 2021; Richards et al. 2020). Interestingly, although CITES have documented numerous illegal movements of *A. anguilla* products into the EU (Stein et al. 2021), a similar DNA barcoding study conducted within Europe found that less than 1% of imported eel products contained European eel (Stein et al. 2021), possibly indicating that Chinese exporters are wary of trading *A. anguilla* into the EU, in the knowledge that it violates EU legislation in addition to CITES regulations (Stein et al. 2021).

Genetic diagnostic tools have also detected many other instances of trafficked *A. anguilla* elsewhere. In 2019, Operation 'Eel-Licit', coordinated by Interpol's Wildlife Crime Working Group[79], resulted in large amounts of trafficked European eel being intercepted in shipments from China. Using DNA testing, *A. anguilla* was detected and seized in all participating nations: the US, Canada, Australia and the EU. In total, nearly 600,000 CITES specimens (filets) were seized (USFWS 2020; GoC 2021; Stein et al. 2021).

Recent developments in DNA diagnostics technology mean that more field-friendly forensics instruments may soon come into general use. Real-time polymerase chain reaction (rtPCR) diagnostic tools will potentially be able to deliver reliable results at a much reduced cost (< US$1.00 per sample), in comparison to existing forensics tools. They will also be able to deliver results in a much shorter timeframe (~ 2 hours) since they can be used in situ, thus obviating the need to send tissue samples to a laboratory. During field trials in Hong Kong, a mobile rtPCR prototype device enabled the first successful eel smuggling prosecution in the territory (Cardeñosa et al. 2019). However, experts warn that as DNA tools develop and become more widely used for enforcement purposes, it may mean that traffickers simply switch to moving eels through countries that do not have the capacity to implement such technology (pers. comm., Matthew Gollock, Ph.D., ZSL Marine and Freshwater Conservation Programme Manager, Chair of IUCN SSC Anguillid Eel Specialist Group, May 2021).

When trafficking is supressed in one place, it escalates elsewhere

Commensurate with the decline in *A. anguilla* glass eel exports to East Asia is an evident uptick in importation of other juvenile anguillids, particularly *A. rostrata* but also tropical species such as *A. bicolor* (Richards et al. 2020; CITES 2018c). As shown in Figure 19, eel fry that are imported into East Asia from the Americas are most likely *A. rostrata*; these originate in the US, Canada, Haiti, Cuba, the Dominican Republic and, more recently, Jamaica (SSC 2021; Gollock et al. 2018; Benchetrit & McCleave 2016).

Even though many Southeast Asian nations ban glass eel exports, it evidently occurs nonetheless, as such inbound trade is documented in East Asian customs data (Gollock et al. 2018). Southeast Asian-sourced tropical eels, which are most likely *A. bicolor*, come from

[79] https://www.interpol.int/en/Crimes/Environmental-crime/Wildlife-crime

countries such as the Philippines, Indonesia, Vietnam and Malaysia (Shiraishi & Crook 2015). Although trade data are unclear, literature notes that the Philippines and Indonesia would appear to be the main exporters of tropical glass eels into East Asia, and that regulations pertaining to this trade are becoming more stringent in both countries (Richards et al. 2020), although enforcement is evidently problematic. In addition to these, other species of tropical eel are sourced from East/Southern Africa (most likely *A. mossambica*), as well as small quantities from Oceania (most likely *A. australis*) (Shiraishi 2020; Shiraishi & Crook 2015).

A recent CITES report, prepared as a follow-up to an international technical workshop on eels (*Anguilla* spp.), notes that while the demand for tropical eels from Southeast Asia (most likely *A. bicolor* from Philippines and Indonesia) increased significantly in 2012-2013, due to diminished availability of *A. japonica* at that time, this increase was not sustained due to a lack of market preference for this species, both in terms of consumer choice and farming suitability (CITES 2018a). In line with this observation, scientists note that a pattern has emerged whereby, in years when more preferential glass eel sources subside, there is a surge in procurement of alternative eel stocks (Gollock et al. 2018; Chambers et al. 2016a).

American glass eels: Trafficking and traceability issues

Between 2007 and 2016, 98% of reported live eel exports from *A. rostrata* range states have been documented as originating in Canada and the US (Gollock et al. 2018). However, as shown in Figure 22, East Asian trade data for live glass eel imports from the US and Canada exceed the elver landings recorded in both of these North American countries (Crook 2018; Gollock et al. 2018; CITES 2018c). While these discrepancies may be somewhat due to the limitations of present reporting requirements, this situation brings the provenance as well as the legality of many of these shipments into question and suggests that some may be comprised of undocumented, illegal North American catch and/or mis-declared re-exports that have actually been harvested in Central and South America - which may also be derived from undocumented or illegitimate sources (Crook 2018).

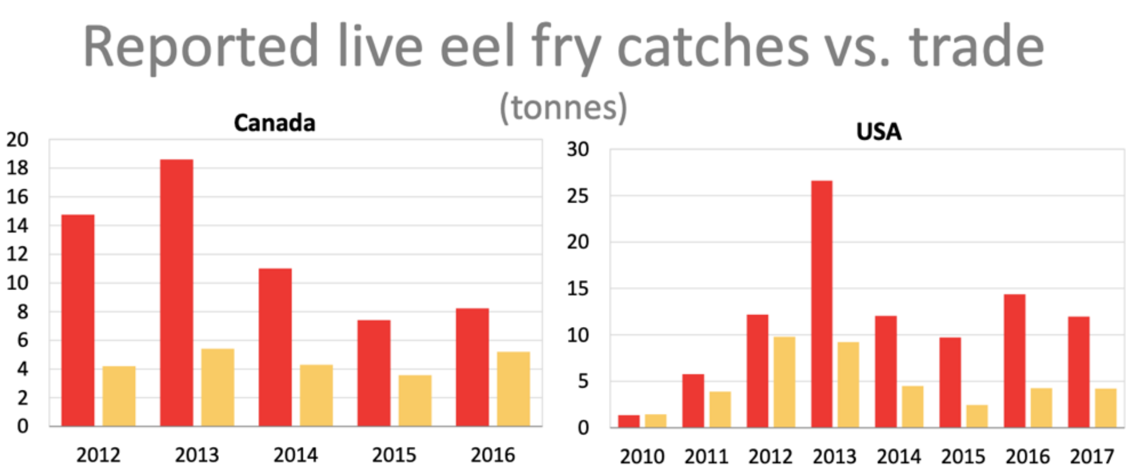

Figure 22: Live eel fry imports from Canada and the USA reported by East Asian Customs (dark orange); Elver landings reported by Canada and the USA, via CITES Notification No. 2018/018 (light orange) (Crook 2018)

In recent years, a number of Caribbean nations have become increasingly relevant to the *A. rostrata* glass eel supply chain, especially Haiti (Crook 2018), where the exporting of glass eels commenced in 2012 as the result of a Korean business initiative (VoA 2015).

Figure 23: East Asian live eel fry imports from the Americas, by source country (kg) (Crook 2018)

	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Canada	5,420	6,536	8,146	13,836	14,751	18,609	11,004	7,403	8,221	9,134
USA	2,319	1,461	1,367	5,764	12,188	26,593	12,043	9,707	14,366	11,956
Haiti						626	1,476	1,704	2,340	1,908
Dominican R.					351	875	183	103	40	
Cuba					264	628	106			
C&S America						20	60			
Total	**7,739**	**7,997**	**9,513**	**19,600**	**27,554**	**47,351**	**24,872**	**18,917**	**24,967**	**22,998**

Figure 23 shows the breakdown of live eel imports into East Asia from *A. rostrata* range states, as per East Asian customs data. These data correlate with those shown in Figures 22 and 19 but, as noted above, the values attributed to North America must be considered with some caution, since the majority of glass eels traded into East Asia from the Americas are routed via the US and Canada.

As a result of escalating prices for North American-sourced glass eels in recent years, East Asian imports of Caribbean and Central American-sourced *A. rostrata* have evidently been on the rise – although glass eel recruitment into the south of the species' range is typically comprised of smaller-sized individuals in comparison to those in the north (Shiraishi 2020). This infers that a country-of-origin mis-declaration may be financially advantageous to eel traders transporting southerly-range-sourced American eels into East Asia. In this regard, it is interesting to note the observations of Canadian enforcement officials, who identify Cuba, the Dominican Republic, Haiti, Jamaica and the US as the main country sources of glass eels entering Canada, and further comment that these are sometimes marketed as product of Canada, possibly because this may be considered to be a more desirable country of origin than others (CITES 2018c).

While numerous literature sources concur that scant information is available pertaining to eel fisheries in the southerly part of *A. rostrata's* range (Benchetrit & McCleave 2016; Jessop & Lee 2016; Chambers et al. 2016b), it would appear that glass eel shipments out of the region are on the rise due to the lucrative nature of such trade – which has also reportedly given rise to violence, allegedly including fatalities, in some collection areas (Pinchin 2021). To what extent such trade is deemed illegal in the various jurisdictions involved is also unclear, however, a report pertaining to a recent CITES 'Workshop of Range States of the American Eel,' [80] which provided a questionnaire to 13 range states, notes the following: "*Nine countries reported that there was no regulation on domestic use of eels at present, and eight countries reported that*

[80] The CITES American Eel Range States workshop took place in Santo Domingo in the Dominican Republic, on 4-6 April 2018. The questionnaire noted above was responded to by the following American eel range states: the Bahamas, Belize, Canada, Costa Rica, Cuba, the Dominican Republic, Haiti, Honduras, Jamaica, Mexico, Nicaragua, Panama and the USA.

there was no legislation regarding eel exports. Regarding illegal harvest, 60 per cent of Range States said that this was a problem in their country," (CITES 2018c). This is also echoed in local newspapers: a news article from the Dominican Republic notes that while catch limits have recently been introduced for glass eels, unlicenced fishing is an ongoing problem, spurred on by the rising value of elvers, which increased more than five-fold between 2017 and 2020 [81]. Newspaper articles also indicate that exports from the Dominican Republic have risen a lot in recent years, reporting that they were 1.6 times the allowable amount in 2019; glass eel catches in Haiti are also reported to have risen substantially, initiating a tightening of regulations in both countries[82, 83,84], although the efficacy of enforcement is unknown.

In 2021, a follow-up Workshop of Range States of the American Eel was organized, and a subsequent report was prepared (SCC 2021), which includes country presentation summaries from Dominican Republic, Haiti and Jamaica. Haiti is described as having a very large glass eel export market, however the fishery lacks catch quotas and does not have any data collection, management, or enforcement measures in place. This section also reports that exporters in Haiti, who are either Haitian or East Asian, are subject to a glass eel export quota, which is currently set at 6,400 kg. With regards to Dominican Republic, where glass eel have been harvested and exported to East Asia since 1980, concerns about illegal activity pertaining to glass eel fisheries are noted, both in terms of these activities themselves and the capacity and expertise of authorities to deal with them. Demand and fishing effort is reported to have increased dramatically from 2015 and, while fishers are required to have a permit and there is a maximum export quota in place (150 kg per company and a cumulative maximum cap of 2,500 kg) as well as a designated closed season, there are no available data on the fishery. According to customs data, the country exported ~12 MT of glass eel between 2016 and 2021. In Jamaica, where an export glass eel fishery started in 2013, the recruitment indices are described as having been small for the last seven years, possibly as a result of reduced water flow. Although catch data is collected, it is hard to verify as it is self-reported by fishers. Jamaican glass eel exports, which transit to East Asia via Canada, have reportedly never exceeded 30 kg (SCC 2021).

While clarity surrounding glass eel management is somewhat lacking with regard to southerly *A. rostrata* range states, authorities in both the US and Canada have implemented a number of strategies to monitor their respective elver fisheries and to limit poaching – an activity which has been greatly encouraged in recent years by soaring elver prices. In response to concerns about the health of the eel stock, a quota and swipe-card system were introduced in Maine in 2014 and, since 2015, a quota of 9,688 pounds (4,394 kg) has been in place (ASMFC 2020). This approach has evidently enabled a much greater degree of transparency in glass eel harvesting and trading, effectively making cash payments between buyers and elver-fishers illegal in the

[81] https://eeltown.org/2020/01/17/eeltown-org-weekend-digest-january-17th-2020/
[82] https://eeltown.org/2020/01/31/eeltown-org-weekend-digest-january-31st-2020/
[83] https://www.diariolibre.com/actualidad/medioambiente/exportaciones-de-angulas-se-disparan-en-2019-en-medio-de-la-fiebre-por-su-pesca-CA16707261
[84] https://eeltown.org/2020/01/31/eeltown-org-weekend-digest-january-31st-2020/

State of Maine (Chase 2018). Since these systems were introduced, a considerable reduction in elver-related infractions has been noted (Kaifu et al. 2019; Norchi et al. 2016).

In 2018, as a result of poaching and black-market trade activity detected in Maine, an emergency decision was made to close the state fishery two weeks early to avoid breaching the quota (Ebersole 2018; Chase 2020). ASMFC later reported that the combined total of both Maine and South Carolina's 2018 season remained below Maine's quota limit (ASMFC 2020). Of note, management of the elver fishery in South Carolina is not implemented by the same methods used in Maine, since the reported catch volumes there evidently do not equate to a significant amount, and also because the very limited number of approved fishers means that landings data are treated in confidence in order to protect the proprietary interests of licence holders (Trotter 2021; Kaifu et al. 2019; ASMFC 2014).

Canada also monitors its elver fishery closely as a result of conservation concerns, especially due to the significant declines in recruitment that have been observed in Québec and Ontario (McCleave et al. 2016). Canada's ongoing elver fisheries are located in Nova Scotia and New Brunswick and, since 2005, the quota for these fisheries has been set at 9,960 kg. Licenced elver fishers must document their landings, including weight, river/stream and catch effort, in a logbook, which is in turn inspected and verified by a designated dockside monitor, as are all sales. Individual elver licences, which are non-transferable, specify the waterbodies that can be fished under that licence and the permissible total quota. A cap is also placed on the quantity of elvers that can be harvested from any individual river during the season; catch limit caps have typically been set at 400 kg per river, however some of these river-specific quotas have been revised and re-scaled according to the actual size of each watershed system. A current priority of Canada's Elver Advisory Committee is to strengthen traceability protocols and reporting procedures that occur beyond the initial point of sale; the aim is to provide greater transparency in the onward movement of elvers as they transit to farms in East Asia (DFO 2018; Norchi et al. 2016). Asides from these commercial elver fisheries, indigenous fishing for eel in the DFO Maritimes Region also takes place through the provision of Food, Social and Ceremonial (FSC) licences. Eels caught under these licenses do not need to be reported and sales are not permitted, however, none of these licenses are specifically for elvers as they are provided for large eels (DFO 2018). A recent news article, which comments that elvers are not a fish traditionally or presently consumed by local indigenous peoples, notes that indigenous elver fishing was first observed in 2016. By 2020, the number of indigenous elver fishers had increased significantly, which prompted the DFO to close the season down early that year due to conservation concerns. This closure applied to all fishers, both commercial and indigenous. Since February 2021, FSC American eel licences in the Maritimes now contain a size limitation, which specifies that eels <10 cm cannot be caught, thus these FSC licences now explicitly prohibit the harvesting of glass eels (Withers 2021).

As noted above, the European eel's CITES Appendix II listing is an important tool that greatly assists in the policing of trade movements involving this species, since a CITES certificate is required for the transportation of any life stage of this species outside of its native range (UNODC 2020). To ensure that international trade in the American eel is conducted sustainably, the possibility of a CITES Appendix II listing for this species has also been discussed (DFO 2018). Another possibility is the introduction of a genus wide CITES-listing for all *Anguilla* spp., or an international Memoranda of Understanding or Action Plan for trade in these species (Gollock et al. 2018).

Operation Broken Glass and Operation Vitrum

In 2011, in response to suspected widespread *A. rostrata* glass eel poaching taking place along the US Atlantic seaboard, and the subsequent trafficking of these eels into East Asia, the USFWS' Office of Law Enforcement launched and led Operation Broken Glass: a multi-jurisdictional criminal investigation, which was executed in collaboration with 16 state and federal partners (USFWS 2019). In addition to overharvesting and illegal harvesting, this investigation also targeted entities involved in illegal movements of eel, including interstate transportation as well as international trafficking beyond US borders. The latter also incorporated the falsification of documents to facilitate onward transit of shipments into East Asia. As of April 2019, the undercover aspects of Operation Broken Glass were deemed to have been concluded, resulting in 19 of "*The most prolific dealers and fisherman of illegal juvenile American eels*," being charged and later sentenced with violations of the Lacey Act (USFWS 2019). Passed in 1900, the Lacey Act became the US' first federal law to protect wildlife, enforcing civil and criminal penalties for the illegal trade of animals and plants[85]. Although the Lacey Act carries a maximum jail term of five years, none of the sentences handed down pursuant to these prosecutions exceeded two years (Kaifu et al. 2019). Heftier penalties are evidently also a possibility, however: a recent press release from the US Department of Justice, which describes the detention and pending sentencing of a glass eel smuggler arrested in early 2021, notes a potential maximum imprisonment term of 10 years and a fine of up to $250,000 [86].

While heightened efforts toward tackling domestic *A. rostrata* glass eel poaching and trade have evidently met with some measure of success, at least in North America, another important potential vector of illegal eel movements is that of inbound eel product imports from East Asia. However, there is currently no routine process in place that allows an importing country to detect if an eel product imported from East Asia is legal or not. Even if DNA testing is implemented, it can only verify the illegality of mis-declared European eel imports, due to this species CITES status, whereas if such analysis reveals that the species is American or Japanese eel, then the product is deemed to be legal as there is not yet any traceability mechanism in place to determine otherwise. The morphological similarity of anguillids means that many intermediaries in the eel value chain can easily become unwitting facilitators of wildlife trafficking, since legitimate supply chains are evidently frequently contaminated with illegal eel products (UNODC 2020). Since a great deal of trafficking inevitably goes undetected, the true extent of illegal-eel products traded into North America is unknown (UNODC 2020).

[85] https://www.fws.gov/international/laws-treaties-agreements/us-conservation-laws/lacey-act.html

[86] https://www.justice.gov/usao-ct/pr/resident-hong-kong-who-smuggled-endangered-glass-eels-united-states-pleads-guilty

As discussed earlier, in 2019 Interpol's Wildlife Crime Working Group conducted Operation Eel-Licit, which resulted in large amounts of trafficked European eel being seized in the US, Canada, Australia and the EU (USFWS 2020). Similarly, Canada has an ongoing enforcement effort in place called Operation Vitrum, which is an initiative led by Environment and Climate Change Canada (ECCC). Between October 2017 and May 2018, seven 21-tonne shipments of eel meat that had been imported into British Columbia from Xiamen, China, and which had been declared as American eel, were analyzed and substantial amounts of European eel were subsequently found in five of the seven containers. This CITES violation resulted in a fine of C$163,776 (~US$135,000) for the importing company (GoC 2021).

Shifting patterns of glass eel inputs in China

The shifting pattern of anguillid juveniles used to stock licenced aquaculture ponds in China, from 2008 to 2016, is shown in Figure 24: as can be noted, prior to the EU export ban, Chinese eel farms were predominantly stocked with European glass eels, which comprised 78% of inputs during the 2008-2009 season. Also evident in this chart is the increasing proportion of American glass eel inputs in recent years (UNODC 2020).

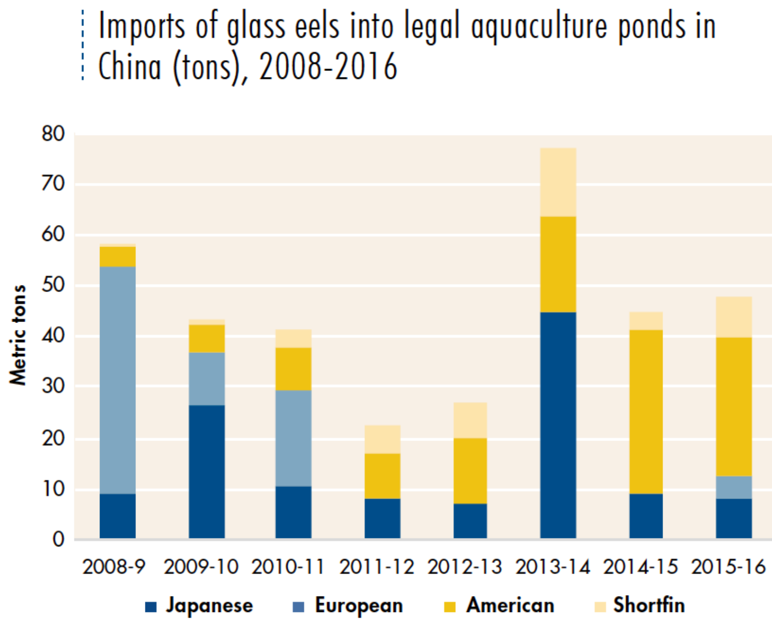

Figure 24: Legally imported glass eels used for farming in China – 2008 to 2016, as per CITES data (UNODC 2020) – Note that here, shortfin refers to *Anguilla bicolor*

Data suggest that China is the principal user of non-*A. japonica* juveniles. In consideration of tropical eels, *A. bicolor* is apparently the most similar in taste and texture to *A. japonica*, thus it is now being exploited more heavily than it was in the past (Chambers et al. 2016a; Shiraishi & Crook 2015). However, farming techniques thus far developed mean that the cultivation of tropical eel species results in relatively higher mortality rates than is experienced with temperate species, therefore, when *A. japonica* is not available, farmers have a preference for *A. anguilla* and *A. rostrata* over *A. bicolor* (pers. comm. Kenzo Kaifu, Ph.D., Professor, Faculty of Law, Chuo University, Director Eel Conservation Research Unit, May 2021). Should culture techniques for tropical species improve, then greater harvesting pressure may be placed on the glass eel stage of tropical eel stocks, particularly if enforcement measures are stepped up in temperate eel regions without equivalent efforts being implemented in tropical zones (Gollock et al. 2018).

The provenance and value of legally imported glass eels used to stock Chinese farms, between 2001 and 2018, are shown in Figure 25. These data indicate that an increase in imports from the US and Canada occurred from 2011 onward, with a spike in trade particularly evident in 2018. Of additional note, Hong Kong is a major glass eel transhipment hub, thus onward exports often misleadingly identify Hong Kong as the country of origin, even though the territory has no glass eel fishery of its own; since 2007, for example, over 70% of Japan's glass eel imports have been documented as coming from Hong Kong (Shiraishi & Crook 2015). Since 2013, there has also reportedly been an increase in Americas-origin glass eel shipments routed via South Korea (CITES 2018c).

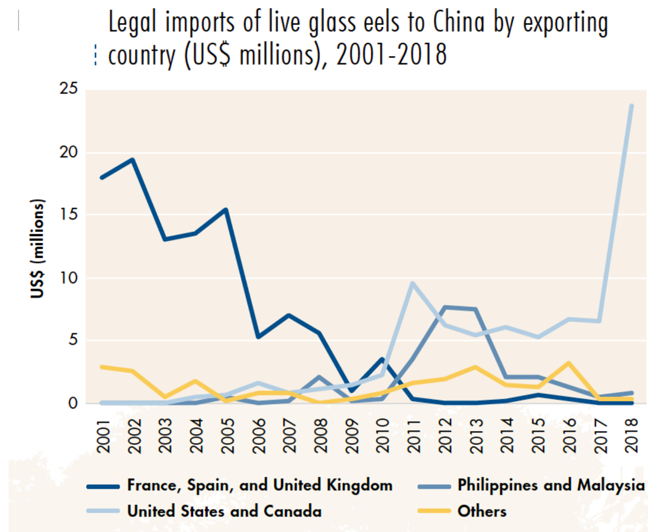

Figure 25: Country source of legally imported glass eels used for farming in China – 2001 to 2018, as per data from UN Comtrade (UNODC 2020)

Eel trafficking and traceability issues within East Asia

While literature notes that some degree of glass eel trade is ongoing between East Asian eel farming nations, official documentation of these transactions is typically absent (Gollock et al. 2018). As a result of this situation, it is extremely challenging to identify fully traceable Japanese eel fry within the region (TSSS 2018; Kaifu 2017). This lack of documentation also obscures the origin and legality of other species of anguillid fry used by the eel farming sector in East Asia (Shiraishi & Crook 2015).

Interestingly, while not specific to juveniles, a recent study that investigated the provenance of Japan's seafood imports determined that around 45-75% of eel products imported from China had originated from IUU fisheries, as had around 22-35% of eel sourced from Taiwan (Pramod et al. 2017). In response to such concerns, in 2020 Japan passed a law to ban the import of IUU fisheries products and implement more effective traceability systems for domestic catches. Once fully implemented, this legislation will bring Japan in line with equivalent laws that are in place in the US and the EU: in 2018, the US established a Seafood Import Monitoring Program and in 2010 the EU's IUU Regulation was enacted (Loew 2020). Despite this initiative, however, this law will evidently not be applied to imported glass eels (pers. comm. Kenzo Kaifu, Ph.D., Professor, Faculty of Law, Chuo University, Director Eel Conservation Research Unit, August 2021).

While the efficacy and impact of Japan's new IUU legislation is as yet unclear, it is apparent that the need to improve traceability within eel supply chains has been acknowledged by numerous stakeholders in Japan, as evidenced, for example, by the Tokyo Sustainable Seafood Symposium event in 2018 (TSSS 2018). Japan has also recently lifted a ban on the export of glass eels, which took effect during the 2021 fishing season; if Taiwan also lifts its export ban, this may help facilitate greater transparency in glass eel supply chains (pers. comm. Hiromi Shiraishi, Independent Consultant, March 2021). Another recent measure announced by Japanese authorities is that penalties for the illegal harvesting of glass eels are to increase: commencing in 2023, the Fisheries Agency will increase fines from ¥100,000 (~US$910) to ¥30 million (~US$273,000) and the maximum period of imprisonment will rise from six months to three years (TJT 2019). Various sources indicate, however, that the general public in Japan is still largely unaware of the conservation issues impacting *A. japonica* (Kaifu 2019; Okamoto 2016).

As discussed previously, the principal regional initiative to conserve the Japanese eel stock is an informal agreement that was made collaboratively, in 2014, between the principal eel farming nations of China, Japan, South Korea and Taiwan: the 'Joint Statement of the Bureau of Fisheries of People's Republic of China, the Fisheries Agency of Japan, the Ministry of Oceans and Fisheries of the Republic of Korea and the Fisheries Agency of Chinese Taipei on International Cooperation for Conservation and Management of Japanese Eel Stock and Other Relevant Eel Species'. Experts note, however, that there has been limited reporting on the progress of this agreement since its inception (Righton et al. 2021) and it is unclear if any material improvements in stock management or supply chain traceability have been realized as yet. In the most recent joint press release pertaining to the agreement, dated June 2020, it is conspicuous that China has declined to participate, as input has only been provided by Japan, South Korea and Taiwan[87]. This is of particular significance to the success, or otherwise, of the agreement, given that China is responsible for 88% of eel production in the region.

Conclusions and Final Score

Since 100% of cultured freshwater eel is produced from wild-caught juveniles, the paramount factor that this Criterion addresses is the conservation status of these species, and whether or not they are considered to be endangered, threatened or protected stocks. This is not a straightforward issue, however, particularly since each species is part of one single, wide-ranging panmictic stock. While drastic declines and extirpation have been noted in many range regions, for all three species considered in this report, in each case there are also some localities where eel are still considered to be relatively abundant.

The IUCN lists the European eel as critically endangered and the Japanese and American eel as endangered; these determinations are based on population decline, a trend that all three stocks exhibit, based on three generation lengths. In addition to these IUCN listings, the European eel is CITES Appendix II listed; in response to this listing, the EU enacted a total import/export ban on all stages of this species while most other CITES Parties explicitly ban the export of the glass eel stage. Besides its IUCN endangered listing, the Japanese eel is also identified as critically endangered in Taiwan and endangered in Japan. The depletion of the Japanese eel stock has also been acknowledged for some time by all four East Asian eel farming nations, China, Japan, South Korea and Taiwan; this consensus led to the issuance of a Joint Statement intended to facilitate collaborative conservation of the stock across its continental

[87] https://www.jfa.maff.go.jp/j/press/sigen/attach/pdf/200717-1.pdf

range – although progress on this initiative may have stalled since China no longer appears to be participating. Concerning the American eel, assessments by US authorities have determined that the stock is depleted in US waters and that it is at or near historically low levels, but that its status does not warrant protection under the Endangered Species Act. In Canada, the American eel was designated as threatened nearly a decade ago, however a decision as to whether or not protection under the Species at Risk act is warranted is still pending. The Province of Ontario comes under different administration in this regard, however, and here the American eel has been protected under the province's Endangered Species Act for many years. In the more southerly range states, a lack of clarity concerning eel stock management measures is evident.

Over the last several decades, the declining trend in Japanese eel recruitment in East Asia has prompted the development of a burgeoning international glass eel supply chain, the volume of which has developed exponentially. The growing demand for cultured eel products is such that legitimate supply chains are evidently insufficient to fulfil demand, a situation which in turn has given rise to a global, highly evolved, lucrative and complex network of eel trafficking. In terms of trade monitoring and control, the only effective mechanism in place at the international level is the CITES listing for European eel. Numerous enforcement efforts have resulted in arrests as a result of this species' CITES status, such as Europol-led Operation Lake, which has successfully intercepted and thwarted many attempts to smuggle large quantities of glass eels out of Europe, and Interpol's Operation 'Eel-Licit', which resulted in large amounts of trafficked European eel being intercepted in shipments from China. During this operation, illegal eel products were genetically identified and seized in all participating nations: the US, Canada, Australia and the EU.

Although there are numerous country-level provisions in place to monitor the harvest and sale of Japanese and American glass eels, these mechanisms evidently fail to control the wildlife trafficking that this sector has become synonymous with in recent years. In the US, for example, although a domestic quota and swipe card system have been implemented, and poachers have been charged with violating the Lacey Act, there is no way of filtering out illegal in-bound eel products shipped from East Asia. Since illegal and legal glass eels are shipped to East Asia together, they are therefore also stocked and harvested together. Subsequently, these comingled legal and illegal eel products are purchased by, and shipped to, international seafood buyers around the world; there is no simple way for consumers to ascertain if the eel they have purchased is legal or not. By its very nature, black market trade is challenging to quantify, thus the extent of glass eel poaching in East Asia is unknown, however, experts estimate that 50% of all glass eels caught in Japan are from illegal, unreported and unregulated (IUU) fisheries. At present, eel supply chains are lacking in a coherent traceability system, and as a result are incontrovertibly tainted with illegally sourced products.

Since these species look alike, the only way to tell them apart during transit is via DNA analysis, a process which is seldom implemented as it is time consuming and expensive. On the occasions that DNA forensics tools are implemented, such as during internationally co-ordinated counter-wildlife trafficking operations, they can only be used to make a prosecution if European eel specimens are detected, since the Japanese and American eel are not CITES listed. Concealment methods for shipping illegal eels are typically well-considered, with legal species mixed in with illegal, thus trafficked Japanese and American glass eels, as well as the eel products they are subsequently processed into, are especially challenging to detect. As a result, much of this illicit trade goes undetected as there is currently no routine way to tell legally sourced eel products apart from those which have been obtained otherwise, via IUU fishing.

Because 100% of farmed eel in East Asia is dependent on wild caught glass eels, much of which is procured from IUU fisheries and endangered or critically endangered stocks, the final numerical score for Criterion 8X – Source of Stock is a deduction of -10 out of -10 and a Critical ranking.

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References for 2021 Update

These references pertain to the introduction to this report and to Criterion 8X – i.e., the sections that have been updated in 2021.

AJASEA. 2016. All Japan Association for Sustainable Eel Aquaculture Incorporated: Eels and Japan – For the Sustainable Use of Eel Resources
https://unagikiko.jp/pdf/panf001en.pdf

ANA. 2019. Maine hosts first land-based eel aquaculture farm – by ANA staff, June 5, 2019
https://www.aquaculturenorthamerica.com/maine-hosts-first-land-based-eel-aquaculture-farm-2341/

ASMFC. 2020. Atlantic States Marine Fisheries Commission – American Eel
http://www.asmfc.org/species/american-eel

ASMFC. 2017. Atlantic States Marine Fisheries Commission: 2017 American Eel Stock Assessment Update
https://www.asmfc.org/uploads/file/59fb5847AmericanEelStockAssessmentUpdateOct2017.pdf

ASMFC. 2014. Atlantic States Marine Fisheries Commission: Addendum IV to the Interstate Fishery Management Plan for American Eel - Approved October 2014
http://www.asmfc.org/uploads/file/57336cfcAmericanEel_AddendumIV_Oct2014.pdf

ASMFC. 2012. Stock Assessment Report No. 12-01 of the Atlantic States Marine Fisheries Commission: American Eel Benchmark Stock Assessment
http://www.asmfc.org/uploads/file/americanEelBenchmarkStockAssessmentReportMay2012.pdf

Aarestrup K, Økland F, Hansen M, Righton D, Gargan P, Castonguay M, Bernatchez L, Howey P, Sparholt H, Pedersen M, Mckinley, R. 2009. Oceanic Spawning Migration of the European Eel (*Anguilla anguilla*). Science (New York, N.Y.). 325. 1660. 10.1126/science.1178120
https://www.researchgate.net/publication/26836170OceanicSpawningMigrationoftheEuropeanEelAnguillaanguilla

Arai K, Itakura H, Yoneta A, Yoshinaga T, Shirotori F, Kaifu K, Kimura S. 2017. Discovering the dominance of the non-native European eel in the upper reaches of the Tone River system, Japan. Fisheries Science. 10.1007/s12562-017-1107-z
https://www.researchgate.net/publication/318217165_Discovering_the_dominance_of_the_non-native_European_eel_in_the_upper_reaches_of_the_Tone_River_system_Japan

Ayala DJ, Munk P, Lundgreen RBC, et al. 2018. Gelatinous plankton is important in the diet of European eel (Anguilla anguilla) larvae in the Sargasso Sea. *Sci Rep*. 2018;8(1):6156. Published 2018 Apr 18. doi:10.1038/s41598-018-24388-x
https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5906606/

BDN. 2019. Bangor Daily News: Eel aquaculture business gets approval to build facility in midcoast town - By Alexander Violo, Lincoln County News • January 17, 2019
https://bangordailynews.com/2019/01/17/business/eel-aquaculture-business-gets-approval-for-build-in-midcoast-town/

Béguer-Pon M. et al. 2015. Direct observations of American eels migrating across the continental shelf to the Sargasso Sea. Nat. Commun. 6:8705 doi: 10.1038/ncomms9705
http://www2.bio.ulaval.ca/labdodson/Papers%20Julian/190.ncomms9705.pdf

Benchetrit J, McCleave JD. 2016. Current and historical distribution of the American eel *Anguilla rostrata* in the countries and territories of the Wider Caribbean, *ICES Journal of Marine Science*, Volume 73, Issue 1, January 2016, Pages 122–134, https://doi.org/10.1093/icesjms/fsv064
https://academic.oup.com/icesjms/article/73/1/122/2457886

Bergmann A. 1978. *Aale gehen an Land: E. Studie zur Biologie d. Aals (1. Aufl)*. Ifland.

Blom J. 2013. Global Aquaculture Advocate: Eel production in Europe, 1 July 2013
https://www.aquaculturealliance.org/advocate/eel-production-in-europe/

Boëtius J, Harding EF. 1985. A re-examination of Johannes Schmidt's Atlantic eel investigations - Dana, Vol. 4, pp. 129-162
https://www.aqua.dtu.dk/english/About/Publications/Dana

Bornarel V, Lambert P, Briand C, Antunes C, Belpaire C, Ciccotti E, Díaz E, Diserud O, Doherty D, Domingos I, Evans D, Graaf M, O'Leary C, Pedersen M, Poole R, Walker A, Wickstro¨m H, Beaulaton L, Drouineau H. 2017. Modelling the recruitment of European eel (Anguilla anguilla) throughout its European range. ICES Journal of Marine Science. 75. 10.1093/icesjms/fsx180.
https://academic.oup.com/icesjms/article/75/2/541/4259273

Briand, Cedric & Bonhommeau, Sylvain & Castelnaud, Gérard & Beaulaton, Laurent. 2007. An appraisal of historical glass eel fisheries and markets: landings, trade routes and future prospect for management.
https://www.researchgate.net/publication/228614981_An_appraisal_of_historical_glass_eel_fisheries_and_markets_landings_trade_routes_and_future_prospect_for_management

CCAR. 2020. University of Maine - Center for Co-operative Aquaculture Research – American eel (*Anguilla rostrata*)
https://umaine.edu/cooperative-aquaculture/american-eels-anguilla-rotrata/

CITES. 2018a. International technical workshop on eels (*Anguilla* spp.) Workshop Report https://cites.org/sites/default/files/eng/com/ac/30/E-AC30-18-01-A3.pdf

CITES. 2018b. Convention on International Trade in Endangered Species of Wild Fauna and Flora - Sc70 Inf. 45: Updated Information on Illegal Trade in European Eel (*Anguilla Anguilla*), Seventieth meeting of the Standing Committee Rosa Khutor, Sochi (Russian Federation), 1-5 October 2018
https://cites.org/sites/default/files/eng/com/sc/70/Inf/E-SC70-Inf-45.pdf

CITES. 2018c. Convention on International Trade in Endangered Species of Wild Fauna and Flora - AC30 Doc. 18.2: Report of the Workshop of Range States of the American Eel, Thirtieth meeting of the Animals Committee Geneva (Switzerland), 16-21 July 2018
https://cites.org/sites/default/files/eng/com/ac/30/E-AC30-18-02.pdf

CITES. 2018d. Convention on International Trade in Endangered Species of Wild Fauna and Flora - AC30 Inf. 19: Thirtieth meeting of the Animals Committee Geneva (Switzerland), 16-21 July 2018 - JOINT PRESS RELEASE ON EELS
https://cites.org/sites/default/files/eng/com/ac/30/Inf/E-AC30-Inf-19.pdf

COSEWIC. 2006. COSEWIC assessment and status report on the American eel *Anguilla rostrata* in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa. x + 71 pp. (www.sararegistry.gc.ca/status/status_e.cfm)
https://www.sararegistry.gc.ca/virtual_sara/files/cosewic/sr_american_eel_e.pdf

Cairns DK, Chaput G, Poirier LA, Avery TS, Castonguay M, Mathers A, Casselman JM, Bradford RG, Pratt T, Verreault G, Clarke K, Veinott G, Bernatchez L. 2014. Recovery Potential Assessment for the American Eel (Anguilla rostrata) for eastern Canada: life history, distribution, reported landings, status indicators, and demographic parameters. DFO Can. Sci. Advis. Sec. Res. Doc. 2013/134. xiv + 157 p.
https://waves-vagues.dfo-mpo.gc.ca/Library/360883.pdf

Cardeñosa D, Gollock MJ, Chapman DD. 2019. Development and application of a novel real-time polymerase chain reaction assay to detect illegal trade of the European eel (*Anguilla anguilla*). *Conservation Science and Practice*. 2019; 1:e39. https://doi.org/10.1111/csp2.39
https://conbio.onlinelibrary.wiley.com/doi/full/10.1111/csp2.39

Case JH. 2018. Global Aquaculture Advocate: American Unagi brings eel farming back 'home', by Julie H Case - 18 June 2018
https://www.aquaculturealliance.org/advocate/american-unagi-brings-eel-farming-back-home/

Castonguay M, Durif CMF. 2016. Understanding the decline in anguillid eels, *ICES Journal of Marine Science*, Volume 73, Issue 1, January 2016, pp 1-4
https://academic.oup.com/icesjms/article/73/1/1/2458925

Chambers WB, Freestone D, Gollock M, Walker A. 2016a. American Eel: A Symposium. Session Four, 21 Ocean & Coastal L.J. 87 (2016).
Available at: http://digitalcommons.mainelaw.maine.edu/oclj/vol21/iss1/7
https://digitalcommons.mainelaw.maine.edu/cgi/viewcontent.cgi?article=1328&context=oclj

Chambers WB, Freestone D, Norchi CH, Thaler JA, VanderZwaag D. 2016b. American Eel: A Symposium. Session Six, 21 Ocean & Coastal L.J. 143 (2016).
https://digitalcommons.mainelaw.maine.edu/cgi/viewcontent.cgi?article=1330&context=oclj

Chaput G, Cairns DK, Bastien-Daigle S, LeBlanc C, Robichaud L, Turple J, Girard C. 2014. Recovery Potential Assessment for the American Eel (*Anguilla rostrata*) for eastern Canada: mitigation options. DFO Can. Sci. Advis. Sec. Res. Doc. 2013/133. v + 30 p.
https://waves-vagues.dfo-mpo.gc.ca/Library/360886.pdf

Chase C. 2020. Nine Mainers win a new elver license out of over 3,600 applicants - by Chris Chase, March 4 2020
https://www.seafoodsource.com/news/supply-trade/nine-mainers-win-a-new-elver-license-out-of-over-3-600-applicants?utm_source=marketo&utm_medium=email&utm_campaign=newsletter&utm_content=newsletter&mkt_tok=eyJpIjoiWkRsbU5ERmxaR1kzTTJVMiIsInQiOiJpQlgzaVlhV0RtZVJDZjgxWFdiUWJsckJMU2pCK1NiTlJEODE0TForNEhxVUluTUF0eEh1VG54WE43OHdsOUlBYWQ0ZjNNMFBQOVFUcldyY2kzM1wvS1NQNlA5MHhibHI2R3paRUZiRE5MNkRYaVNGSUJ1STE5NnIrRlwvNkNrOTNYIn0%3D

Chase C. 2018. Maine elver catch surpasses USD 21 million - by Chris Chase, May 22 2018
https://www.seafoodsource.com/news/supply-trade/maine-elver-catch-surpasses-usd-21-million

Chen J-Z, Huang S-L, Han Y-S. 2014. Impact of long-term habitat loss on the Japanese eel Anguilla japonica. Estuarine Coastal and Shelf Science. in press. 10.1016/j.ecss.2014.06.004.
https://www.researchgate.net/publication/262804743Impactoflong-termhabitatlossontheJapaneseeelAnguillajaponica

Chow S, Kurogi H, Mochioka N, Kaji S, Okazaki M, Tsukamoto K. 2008. Discovery of mature freshwater eels in the open ocean. Fisheries Science. 75. 257-259. 10.1007/s12562-008-0017-5.
https://www.researchgate.net/publication/225712712Discoveryofmaturefreshwatereelsintheopenocean

Cohen A, Ross NW, Smith PM, Fawcett JP. 2017. Analysis of 17β-estradiol, estriol and estrone in American eel (*Anguilla rostrata*) tissue samples using liquid chromatography coupled to electrospray differential ion mobility tandem mass spectrometry. Rapid Communications in Mass Spectrometry, 31(10), 842–850. doi:10.1002/rcm.7853
https://onlinelibrary.wiley.com/doi/abs/10.1002/rcm.7853

Crook V. 2018. Overview of recent trade in *Anguilla* spp., focusing on American Eel range States - American Eel Range States Workshop Santo Domingo, Dominican Republic, 4-6 April, 2018 http://www.sargassoseacommission.org/storage/Vicki_Crook_presentation_VC3.pdf

Crook V, Nakamura M. 2013. Glass eels: assessing supply chain and market impact of a CITES listing on Anguilla species, TRAFFIC Bull. 25 (2013) 24–30. http://www.sargassoseacommission.org/storage/traffic_pub_bulletin_25_1_glass_eels.pdf

DFO. 2018. Elver integrated fisheries management plan (evergreen) Maritimes Region https://www.dfo-mpo.gc.ca/fisheries-peches/ifmp-gmp/elver-anguille/index-eng.html

DFO. 2014. Recovery potential assessment of American Eel (Anguilla rostrata) in eastern Canada. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2013/078. http://canadianeel.org/wp-content/uploads/2014/11/CSAS-Advisory-Report.-2013-Recovery-potential-assessment-of-American-eel.-CSAS-Res-Doc-2013078.pdf

Degani G. 2016. A Model of Hormonal and Environmental Involvement in Growth and Sex Differentiation in European Eel (*Anguilla Anguilla*). *Advances in Biological Chemistry*, **6**, 141-145. doi: 10.4236/abc.2016.64012. https://scirp.org/journal/paperinformation.aspx?paperid=70143

Deinet S, Scott-Gatty, K, Rotton H, Twardek WM, Marconi V, McRae, L, Baumgartner LJ, Brink, K, Claussen JE, Cooke SJ, Darwall W, Eriksson BK, Garcia de Leaniz C, Hogan Z, Royte, J, Silva LGM, Thieme ML, Tickner D, Waldman, J, Wanningen H, Weyl, OLF, Berkhuysen A. 2020. The Living Planet Index (LPI) for migratory freshwater fish - Technical Report. World Fish Migration Foundation, The Netherlands. https://worldfishmigrationfoundation.com/wp-content/uploads/2020/07/LPI_report_2020.pdf

Dekker W. 2020. The Ecologist: Protecting the European eel by Willem Dekker, 15 January 2020 https://theecologist.org/2020/jan/15/protecting-european-eel?fbclid=IwAR2SSkwvpRDDzGUKk013pr6S8y55r7ZqJvJArhEaK7iDEcJ3wCockYo9ZHA

Dekker W. 2018. The history of commercial fisheries for European eel commenced only a century ago. Fisheries Management and Ecology. 26. 10.1111/fme.12302. https://www.researchgate.net/publication/326477711Dekker2018Thehistoryofcommercialfish eriesforEuropeaneelcommencedonlyacenturyago

Dekker W, Beaulaton L. 2016a. Climbing back up what slippery slope? Dynamics of the European eel stock and its management in historical perspective, ICES Journal of Marine Science, Volume 73, Issue 1, January 2016, Pages 5–13, https://doi.org/10.1093/icesjms/fsv132 https://academic.oup.com/icesjms/article/73/1/5/2458735

Dekker W, Beaulaton L. 2016b. Faire mieux que la nature? The History of Eel Restocking in Europe - *Environment and History* 22 (2016): 255-300. doi: 10.3197/096734016X145743293144 https://www.ingentaconnect.com/content/whp/eh/2016/00000022/00000002/art00006

Dekker W. 2004. Did lack of spawners cause the collapse of the European eel, *Anguilla anguilla*? Fisheries Management and Ecology, 10: 365-376. https://doi.org/10.1111/j.1365-2400.2003.00352.x
https://edepot.wur.nl/25418#page=65

Dekker W. 2003. Status of the European Eel Stock and Fisheries. Eel biology / Aida, K., K. Tsukamoto, K. Yamauchi. 10.1007/978-4-431-65907-517.
https://www.researchgate.net/publication/40798533_Status_of_the_European_Eel_Stock_and_Fisheries

Dekker W, Van Os B, Van Willigen J. 1998. Minimal and Maximal size of eel. l'Anguille Européenne 10e Réunion du groupe de travail anguille EIFAC/ICES 23-27/09/96, IJmuiden (Pays-Bas). Bull. Fr. Peche Piscic.(1998)349:195-197. 349. 10.1051/kmae:1998044.
https://www.researchgate.net/publication/40155140_Minimal_and_Maximal_size_of_eel

Diggins A. 2020. Wired Magazine article: Inside the takedown of Europe's multi-billion pound eel mafia - By Alex Diggins, Friday 12 June 2020
https://www.wired.co.uk/article/illegal-eel-trade-smuggling

Drouineau H, Durif C, Castonguay M, Mateo M, Rochard E, Verreault G., … Lambert, P. 2018. *Freshwater eels: A symbol of the effects of global change. Fish and Fisheries.* doi:10.1111/faf.12300
https://onlinelibrary.wiley.com/doi/10.1111/faf.12300

E360. 2013. Yale Environment 360 online magazine - In Japan, Captive Breeding May Help Save the Wild Eel - By Winifred Bird • October 10, 2013
E360 is published at the Yale School of Forestry & Environmental Studies
https://e360.yale.edu/features/injapancaptivebreedingmayhelpsavethewildeel

Ebersole R. 2018. National Geographic – 19 Eel Smugglers Sentenced, But Lucrative Trade Persists. Published June 27, 2018
https://www.nationalgeographic.com/animals/article/wildlife-watch-eel-smuggling-operation-broken-glass-maine

Ebersole R. 2017. National Geographic – Wildlife Watch: Inside the Multimillion-Dollar World of Eel Trafficking. Published June 7, 2017
https://www.nationalgeographic.com/animals/article/glass-eel-elver-trafficking-fishing-unagi

Egusa S. 1979. Notes on the culture of the European eel (Anguilla anguilla L.) in Japanese eel-farming ponds.

https://www.ices.dk/sites/pub/Publication%20Reports/Marine%20Science%20Symposia/Phase%202/Rapport%20et%20Proces-Verbaux%20des%20Reunions%20-%20Volume%20174%20-%201979%20-%20Partie%2009%20de%2023.pdf

Enbody ED, Pettersson MEC. Sprehn G, Palm S, Wickström H, Andersson L. 2021. Ecological adaptation in European eels is based on phenotypic plasticity - Proceedings of the National Academy of Sciences Jan 2021, 118 (4) e2022620118; DOI:10.1073/pnas.2022620118 https://www.pnas.org/content/118/4/e2022620118

Espiñeira M, Vieites J. 2015. Genetic system for an integral traceability of European eel (Anguilla anguilla) in aquaculture and seafood products: authentication by fast real-time PCR. European Food Research and Technology. 242. 10.1007/s00217-015-2514-y. https://www.researchgate.net/publication/282538628_Genetic_system_for_an_integral_traceability_of_European_eel_Anguilla_anguilla_in_aquaculture_and_seafood_products_authentication_by_fast_real-time_PCR

Eurofish. 2020. Eurofish Magazine: Scientists in Denmark come closer to breeding European eel in captivity, August 2020 https://www.eurofishmagazine.com/sections/country-profiles/item/748-scientists-in-denmark-come-closer-to-breeding-european-eel-in-captivity

Europol. 2020. Europol Press Release: The Most Recent Fishing Season Sees 108 Smugglers Arrested and over 2 Tonnes of Glass Eels Seized in Europe - 04 June 2020 https://www.europol.europa.eu/newsroom/news/most-recent-fishing-season-sees-108-smugglers-arrested-and-over-2-tonnes-of-glass-eels-seized-in-europe

Europol. 2019. Europol Press Release: Over 5 Tonnes of Smuggled Glass Eels Seized in Europe this Year - 06 November 2019 https://www.europol.europa.eu/newsroom/news/over-5-tonnes-of-smuggled-glass-eels-seized-in-europe-year

Europol. 2018a. Europol Press Release: Glass Eel Traffickers Earned More Than Eur 37 Million from Illegal Exports to Asia - 06 April 2018 https://www.europol.europa.eu/newsroom/news/glass-eel-traffickers-earned-more-eur-37-million-illegal-exports-to-asia

Europol. 2018b. Europol Press Release: 3.4 Tonnes of Seized Glass Eels Reintroduced into their Natural Habitat - 22 June 2018 https://www.europol.europa.eu/newsroom/news/34-tonnes-of-seized-glass-eels-reintroduced-their-natural-habitat

Europol. 2017. Europol Press Release: EU Law Enforcement Step Up Efforts to Protect the Environment – 48 Arrested for Trafficking Endangered Species - 23 June 2017 https://www.europol.europa.eu/newsroom/news/eu-law-enforcement-step-efforts-to-protect-environment-—-48-arrested-for-trafficking-endangered-species

FAO. 2021. Fishery and Aquaculture Statistics. Global aquaculture production 1950-2019 (FishstatJ). In: FAO Fisheries Division [online]. Rome. Updated 2021. www.fao.org/fishery/statistics/software/fishstatj/en

FAO. 2005. Cultured Aquatic Species Information Programme. Anguilla japonica. Cultured Aquatic Species Information Programme. Text by Xie, J. In: FAO Fisheries and Aquaculture Department [online]. Rome. Updated 13 January 2005. [Cited 20 March 2020]. http://www.fao.org/fishery/culturedspecies/Anguillajaponica/en

FDA. 2021. *Fish and fishery products hazards and control guidance*. Retrieved from: https://www.fda.gov/media/80637/download

Flaherty N. 2018. Why Maine Is The Only State In The US With A 'Significant' Elver Fishery - Maine Public | By Nora Flaherty, Published May 1, 2018 https://www.mainepublic.org/business-and-economy/2018-05-01/why-maine-is-the-only-state-in-the-us-with-a-significant-elver-fishery

Fletcher R. 2018. The Fish Site - The real eel: a guide to eel farming, 7 June 2018 https://thefishsite.com/articles/the-real-eel-eel-farming-explained

Foster SJ, Vincent ACJ. 2021. Holding governments accountable for their commitments: CITES Review of Significant Trade for a very high-volume taxon, Global Ecology and Conservation, Volume 27, 2021, e01572, ISSN 2351-9894, https://doi.org/10.1016/j.gecco.2021.e01572. https://www.sciencedirect.com/science/article/pii/S2351989421001220

Freese M, Rizzo LY, Pohlmann J-D, Marohn L, Witten PE, Gremse F, Rütten S, Güvener N, Michael S, Wysujack K, Lammers T, Kiessling F, Hollert H, Hanel R, Brinkmann M. 2019. Bone resorption and body reorganization during maturation induce maternal transfer of toxic metals in anguillid eels - Proceedings of the National Academy of Sciences Jun 2019, 116 (23) 11339-11344; DOI:10.1073/pnas.1817738116
https://www.pnas.org/content/116/23/11339

Freestone D, Norchi C, VanderZwaag D. 2016. American Eel: A Symposium. Introduction, 21 Ocean & Coastal L.J. 1 (2016). Available at:
http://digitalcommons.mainelaw.maine.edu/oclj/vol21/iss1/2
https://digitalcommons.mainelaw.maine.edu/cgi/viewcontent.cgi?referer=https://www.google.com/&httpsredir=1&article=1323&context=oclj

GoC. 2021. Government of Canada: British Columbia-based import company ordered to pay $163,776 fine for illegally importing European eel meat – published March 4, 2021 – Vancouver, British Columbia – Environment and Climate Change Canada https://www.canada.ca/en/environment-climate-change/services/environmental-enforcement/notifications/british-columbia-import-company-ordered-pay-fine-illegally-importing-european-eel-meat.html

GoC. 2016. Government of Canada: The American Eel – Date modified: 2016-12-19 https://www.dfo-mpo.gc.ca/species-especes/publications/sara-lep/eel-anguille/index-eng.html

Gollock M, Shiraishi H, Carrizo S, Crook V, Levy E. 2018. Status of non-CITES listed anguilid eels - Delivered by the Zoological Society of London
https://cites.org/eng/node/80318
https://cites.org/sites/default/files/eng/com/ac/30/E-AC30-18-01-A2.pdf

Hamidoghli A, Bae J, Won S, Lee S, Kim D, Bai SC. 2019. A Review on Japanese Eel (Anguilla japonica) Aquaculture, With Special Emphasis on Nutrition, Reviews in Fisheries Science & Aquaculture, 27:2, 226-241, DOI: 10.1080/23308249.2019.1583165
https://www.tandfonline.com/doi/full/10.1080/23308249.2019.1583165?scroll=top&needAccess=true

Hein T. 2020. Aquaculture North America: U.S. farmer aims to displace frozen eel imports - April 1, 2020, By Treena Hein
https://www.aquaculturenorthamerica.com/u-s-farmer-aims-to-displace-frozen-eel-imports/

Higuchi M, Mekuchi M, Hano T, Imaizumi H. 2019. Trans-omics analyses revealed differences in hormonal and nutritional status between wild and cultured female Japanese eel (Anguilla japonica). PLOS ONE 14(5): e0209063. https://doi.org/10.1371/journal.pone.0209063
https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0209063

ICES. 2021. Workshop on the future of eel advice (WKFEA). ICES Scientific Reports. 3:13. 67 pp. https://doi.org/10.17895/ices.pub.5988
https://www.ices.dk/sites/pub/Publication%20Reports/Expert%20Group%20Report/Fisheries%20Resources%20Steering%20Group/2021/WKFEA_2021.pdf

ICES. 2020a. Joint EIFAAC/ICES/GFCM Working Group on Eels (WGEEL). ICES Scientific Reports. 2:85. 223 pp. http://doi.org/10.17895/ices.pub.5982
https://www.ices.dk/sites/pub/Publication%20Reports/Expert%20Group%20Report/Fisheries%20Resources%20Steering%20Group/2020/WGEEL/2020_WGEEL.pdf

ICES. 2020b. ICES Advice on fishing opportunities, catch, and effort Ecoregions in the Northeast Atlantic - Published 30 October 2020
https://www.ices.dk/sites/pub/Publication%20Reports/Advice/2020/2020/ele.2737.nea.pdf

ICES. 2019. European eel (*Anguilla anguilla*) throughout its natural range. *In* Report of the ICES Advisory Committee, 2019. ICES Advice 2019, ele.2737.nea.
http://www.ices.dk/sites/pub/Publication%20Reports/Advice/2019/2019/ele.2737.nea.pdf

ICES. 2016. Report of the Workshop on Eel Stocking (WKSTOCKEEL), 20–24 June 2016, Toomebridge, Northern Ireland, UK. ICES CM 2016/SSGEPD:21. 75 pp. https://www.ices.dk/sites/pub/Publication%20Reports/Expert%20Group%20Report/SSGEPD/2016/01%20WKSTOCKEEL%20-%20Report%20of%20the%20Workshop%20on%20Eel%20Stocking.pdf

ICES. 2015. ICES Special Request Advice Northeast Atlantic: 9.2.3.2 EU request on criteria for CITES non-detriment finding for European eel (*Anguilla anguilla*) - Published 30 April 2015 https://www.ices.dk/sites/pub/Publication%20Reports/Advice/2015/Special_Requests/EU_CITES_NDF_eel.pdf

ICES. 2007. *ICES Journal of Marine Science*, Volume 64, Issue 7, October 2007, Pages 1402–1413, https://doi.org/10.1093/icesjms/fsm071 https://academic.oup.com/icesjms/article/64/7/1402/726053

ITC. 2021. International Trade Centre – Trade Map https://www.trademap.org/Index.aspx

JN. 2021. Jornal de Notícias: Três detidos por captura ilegal de meixão em operação internacional – April 14, 2021 https://www.jn.pt/justica/tres-detidos-por-captura-ilegal-de-meixao-em-operacao-internacional-13568195.html

JWCS. 2017. Japan Wildlife Conservation Society: Habitat status, aquaculture and trade in Japan https://www.jwcs.org/en/wp-content/uploads/sites/2/ENEelsinJapan.pdf

Jacoby D, Casselman J, DeLucia M, Gollock M. 2017. *Anguilla rostrata* (amended version of 2014 assessment). *The IUCN Red List of Threatened Species* 2017: e.T191108A121739077. https://dx.doi.org/10.2305/IUCN.UK.2017-3.RLTS.T191108A121739077.en. Downloaded on 26 April 2021. https://www.iucnredlist.org/species/191108/121739077

Jacoby D, Casselman J, Crook V, Delucia MB, Ahn H, Kaifu K, Kurwie T, Sasal P, Silfvergrip A, Smith K, Uchida K, Walker A, Gollock M. 2015. Synergistic patterns of threat and the challenges facing global anguillid eel conservation. Global Ecology and Conservation. 4. 321-333. 10.1016/j.gecco.2015.07.009 https://www.sciencedirect.com/science/article/pii/S2351989415000827

Jarvis B. 2020. The New Yorker: Where Do Eels Come From? By Brooke Jarvis, May 18, 2020 https://www.newyorker.com/magazine/2020/05/25/where-do-eels-come-from

Jellyman DJ. 2021. An enigma: how can freshwater eels (*Anguilla* spp.) be such a successful genus yet be universally threatened?. *Rev Fish Biol Fisheries* (2021). https://doi.org/10.1007/s11160-021-09658-8 https://link.springer.com/article/10.1007/s11160-021-09658-8

Jessop B, Lee L. 2016. American Eel (Anguilla rostrata) Stock Status in Canada and the United States. 10.1201/b19925-14. https://www.researchgate.net/publication/313632811AmericanEelAnguillarostrataStockStatusinCanadaandtheUnitedStates

Jessop B. 1998. Geographic and seasonal variation in biological characteristics of American eel elvers in the Bay of Fundy area and on the Atlantic coast of Nova Scotia. Canadian Journal of Zoology. 76. 2172-2185. 10.1139/z98-169. https://www.researchgate.net/publication/238041943_Geographic_and_seasonal_variation_in_biological_characteristics_of_American_eel_elvers_in_the_Bay_of_Fundy_area_and_on_the_Atlantic_coast_of_Nova_Scotia

Kaifu K. 2019. Challenges in assessments of Japanese eel stock, Marine Policy, Volume 102, 2019, Pages 1-4, ISSN 0308-597X, https://doi.org/10.1016/j.marpol.2019.02.005. https://www.sciencedirect.com/science/article/pii/S0308597X18308169

Kaifu K, Yokouchi K. 2019. Increasing or decreasing? - Current status of the Japanese eel stock, Fisheries Research, Volume 220, 2019, 105348, ISSN 0165-7836, https://doi.org/10.1016/j.fishres.2019.105348 https://www.sciencedirect.com/science/article/abs/pii/S0165783619302036

Kaifu K, Stein F, Dekker W, Walker N, Dolloff CA, Steele K, Aguirre AA, Nijman V, Siriwat P, Sasal P. 2019. Global exploitation of freshwater eels (genus Anguilla): fisheries, stock status and illegal trade. https://www.researchgate.net/publication/336738987_Global_exploitation_of_freshwater_eels_genus_Anguilla_fisheries_stock_status_and_illegal_trade

Kaifu K, Yokouchi K, Higuchi T. *et al.* 2018. Depletion of naturally recruited wild Japanese eels in Okayama, Japan, revealed by otolith stable isotope ratios and abundance indices. *Fish Sci* **84,** 757–763 (2018). https://doi.org/10.1007/s12562-018-1225-2 https://link.springer.com/article/10.1007/s12562-018-1225-2

Kaifu K. 2017. Thoughts on eel conservation during Japan's biggest eel-eating day of the year – 2017.08.08 - Kenzo Kaifu, Associate Professor, Faculty of Law, Chuo University http://global.chuo-u.ac.jp/english/features/2017/08/9518/

Kloppmann M. 2003. Body Structure and Functions. In The Eel (eds F.-W. Tesch and J. Thorpe). https://doi.org/10.1002/9780470995389.ch1 https://onlinelibrary.wiley.com/doi/book/10.1002/9780470995389

Knott K. 2021. South China Morning Post: Most eel eaten in Hong Kong sushi restaurants is from endangered species, study finds by Kylie Knott, June 1, 2021 https://www.scmp.com/lifestyle/food-drink/article/3134922/almost-90pc-eel-products-sold-hong-kong-sushi-restaurants

Loew C. 2020. SeafoodSource: Japanese legislature passes law to ban import of IUU seafood - By Chris Loew, December 9, 2020
https://www.seafoodsource.com/news/supply-trade/japanese-legislature-passes-law-to-curb-iuu-fishing

MAFF. 2020. Ministry of Agriculture, Forestry and Fisheries (Japan): Joint Press Release - On the occasion of the Thirteenth Meeting of the Informal Consultation on International Cooperation for Conservation and Management of Japanese Eel Stock and Other Relevant Eel Species, 29 June 2020
https://www.jfa.maff.go.jp/j/press/sigen/attach/pdf/200717-1.pdf

MAFF. 2014. Ministry of Agriculture, Forestry and Fisheries (Japan): Joint Statement of the Bureau of Fisheries of People's Republic of China, the Fisheries Agency of Japan, the Ministry of Oceans and Fisheries of the Republic of Korea and the Fisheries Agency of Chinese Taipei on International Cooperation for Conservation and Management of Japanese Eel Stock and Other Relevant Eel Species - September 17, 2014
https://www.jfa.maff.go.jp/j/saibai/pdf/140917jointstatement.pdf

Masuda Y, Imaizumi H, Oda K, Hashimoto H, Usuki H, Teruya K. 2012. Artificial Completion of the Japanese Eel, *Anguilla japonica*, Life Cycle: Challenge to Mass Production
水研センター研報，第35号，111-117，平成24年 Bull. Fish. Res. Agen. No. 35, 111-117, 2012
https://www.fra.affrc.go.jp/bulletin/bull/bull35/35-13.pdf

McCartney E. 1920. Spontaneous Generation and Kindred Notions in Antiquity. *Transactions and Proceedings of the American Philological Association, 51*, 101-115. doi:10.2307/282874
https://www.jstor.org/stable/282874?seq=1#metadatainfotabcontents

McCleave J, Cairns D, Costa-Pierce B. 2016. American Eel: A Symposium. Session One, 21 Ocean & Coastal L.J. 7 (2016).
https://digitalcommons.mainelaw.maine.edu/cgi/viewcontent.cgi?article=1325&context=oclj

Miller MJ, Feunteun E, Tsukamoto K. 2016. Did a "perfect storm" of oceanic changes and continental anthropogenic impacts cause northern hemisphere anguillid recruitment reductions?, *ICES Journal of Marine Science*, Volume 73, Issue 1, January 2016, Pages 43–56, https://doi.org/10.1093/icesjms/fsv063
https://academic.oup.com/icesjms/article/73/1/43/2457868

Miller M, Casselman J. 2014. The American Eel: A Fish of Mystery and Sustenance for Humans. 155-169. 10.1007/978-4-431-54529-311
https://link.springer.com/chapter/10.1007/978-4-431-54529-3_11

Miller M. 2009. Ecology of Anguilliform Leptocephali: Remarkable Transparent Fish Larvae of the Ocean Surface Layer. Aqua-bioscience Monographs. 2. 10.5047/absm.2009.00204.0001 https://www.researchgate.net/publication/250395431EcologyofAnguilliformLeptocephaliRemarkableTransparentFishLarvaeoftheOceanSurfaceLayer

Morrison R. 2020. The Atlantic Monthly - America's Hottest Black Market: Inside the Eel Gold Rush – a video by Rachael Morrison, January 3, 2020 https://www.theatlantic.com/video/index/604204/elvers/

Musing L, Shiraishi H, Crook V, Gollock Matthew, Levy E, Kecse-Nagy Katalin. 2018. Implementation of the CITES Appendix II listing of European Eel Anguilla anguilla. https://cites.org/sites/default/files/eng/com/AC/30/E-AC30-18-01-A1.pdf

NOAA. 2021. National Oceanic and Atmospheric Administration - Foreign Fishery Trade Data https://www.fisheries.noaa.gov/national/sustainable-fisheries/foreign-fishery-trade-data

NPR. 2018. National Public Radio - Will Americans Embrace A Zeal For Eel? This Maine Entrepreneur Hopes So - October 15, 2018 https://www.npr.org/sections/thesalt/2018/10/15/656206593/will-americans-embrace-a-zeal-for-eel-this-maine-entrepreneur-hopes-so

NWCU. 2019. National Wildlife Crime Unit (UK) – NWCU and Europol Meet to Combat Illegal Trade in Eels https://www.nwcu.police.uk/news/nwcu-police-press-releases/nwcu-and-europol-meet-to-combat-illegal-trade-in-eels/

Netzler F. 1928. Book: Helsingborgsminnen fran min ungdom – p 333 Ålan

Nijman V, Stein FM. 2021. European eels in restaurants and supermarkets outside Europe, as authenticated by DNA barcoding, conflict with trade regulations and food control requirements (*manuscript submitted*)

Nijman V. 2017. North Africa as a source for European eel following the 2010 EU CITES eel trade ban. Marine Policy. 85. 133-137. 10.1016/j.marpol.2017.06.036. Nijman, Vincent. (2017). North Africa as a source for European eel following the 2010 EU CITES eel trade ban. Marine Policy. 85. 133-137. 10.1016/j.marpol.2017.06.036. https://wildlifetraderesearch.files.wordpress.com/2018/05/nijmanmarinepolicyeel2017.pdf

Norchi C, VanderZwaag D, Dettmers J, Sears RW, Hussey-Bondt L, Waine M. 2016. American Eel: A Symposium. Session Five, 21 Ocean & Coastal L.J. 113 (2016).
Available at: http://digitalcommons.mainelaw.maine.edu/oclj/vol21/iss1/8
https://digitalcommons.mainelaw.maine.edu/cgi/viewcontent.cgi?article=1329&context=oclj

Okamoto K. 2016. The Atlantic Monthly - When an Endangered Species Endangers a Culture by Katie Okamoto, January 12, 2016
https://www.theatlantic.com/science/archive/2016/01/unagi-endangered-eel-japan/423675/

Orth D. 2016. Mysteries of the American Eel, by Don Orth, Virginia Tech Ichthyology blog, March 23, 2016
http://vtichthyology.blogspot.com/2016/03/mysteries-of-american-eel-by-don-orth.html

PRO-EEL. 2014. PRO-EEL - Reproduction of European Eel Towards a Self-Sustained Aquaculture - a collaborative research project receives funding from the European Commission under the Theme "Food, Agriculture and Fisheries, and Biotechnology" of the 7th Framework Programme (Grant Agreement No. 245257)
http://www.pro-eel.eu/about-pro-eel

Pampiglione S, Giannetto S. 2001. 'The Grassi—Calandruccio Controversy. Who is Wrong? Who is Right?', Journal of Medical Biography, 9(2), pp. 81–86. doi: 10.1177/096777200100900205.
https://journals.sagepub.com/doi/abs/10.1177/096777200100900205

Pavitt A, Malsch K, King E, Chevalier A, Kachelriess D, Vannuccini S, Friedman, K. 2021. *CITES and the sea: Trade in commercially exploited CITES-listed marine species.* FAO Fisheries and Aquaculture Technical Paper No. 666. Rome, FAO. https://doi.org/10.4060/cb2971en
http://www.fao.org/documents/card/en/c/cb2971en

Pike C, Crook V, Gollock M. 2020a. *Anguilla anguilla*. *The IUCN Red List of Threatened Species* 2020: e.T60344A152845178. https://dx.doi.org/10.2305/IUCN.UK.2020-2.RLTS.T60344A152845178.en. Downloaded on 19 April 2021.
https://www.iucnredlist.org/species/60344/152845178

Pike C, Kaifu K, Crook V, Jacoby D, Gollock M. 2020b. *Anguilla japonica* (amended version of 2020 assessment). *The IUCN Red List of Threatened Species* 2020: e.T166184A176493270. https://dx.doi.org/10.2305/IUCN.UK.2020-3.RLTS.T166184A176493270.en. Downloaded on 21 April 2021.
https://www.iucnredlist.org/species/166184/176493270

Pinchin K. 2021. The Counter: Slimy, smuggled and worth more than gold: Can one Maine entrepreneur break into the crime-ridden global market for eel? By Karen Pinchin – March 11 2021.
https://thecounter.org/can-one-maine-entrepreneur-break-into-the-crime-ridden-global-market-for-eel/

Pramod G, Pitcher T, Mantha G. 2017. Estimates of illegal and unreported seafood imports to Japan. Marine Policy. 84. 42 - 51. 10.1016/j.marpol.2017.06.032.
http://stopcrabmafia.ru/wp-content/uploads/2017/07/Estimates-of-illegal-and-unreported-seafood-imports-to-Japan.pdf

Pratt TC, Bradford RG, Cairns DK, Castonguay M, Chaput G, Clarke KD, Mathers A. 2014. Recovery Potential Assessment for the American Eel (Anguilla rostrata) in eastern Canada: functional description of habitat. DFO Can. Sci. Advis. Sec. Res. Doc. 2013/132. v + 49 p. http://canadianeel.org/wp-content/uploads/2014/11/Pratt-TC-et-al.-2013.-Recovery-potential-assessment-for-American-eelhabitat-description.-CSAS-Res-Doc-2013132.pdf

Pujolar JM, Jacobsen MW, Als TD, Frydenberg J, Magnussen E, Jónsson B, Jiang X, Cheng L, Bekkevold D, Maes GE, Bernatchez L, Hansen MM. 2014. Assessing patterns of hybridization between North Atlantic eels using diagnostic single-nucleotide polymorphisms. Heredity (Edinb). 2014 Jun;112(6):627-37. doi: 10.1038/hdy.2013.145. Epub 2014 Jan 15. PMID: 24424165; PMCID: PMC4023445.
https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4023445/

Richards JL, Sheng V, Yi CW, Ying CL, Ting NS, Sadovy Y, Baker D. 2020. Prevalence of critically endangered European eel (*Anguilla anguilla*) in Hong Kong supermarkets. Sci Adv. 2020 Mar 4;6(10):eaay0317. doi: 10.1126/sciadv.aay0317. PMID: 32181342; PMCID: PMC7056311. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7056311/

Righton D, Piper A, Aarestrup K, et al. 2021. Important questions to progress science and sustainable management of anguillid eels. *Fish and Fisheries*. 2021; 00: 1– 27. https://doi.org/10.1111/faf.12549
https://onlinelibrary.wiley.com/doi/epdf/10.1111/faf.12549

Righton, D. *et al.* 2016. Empirical observations of the spawning migration of European eels: The long and dangerous road to the Sargasso Sea. *Sci. Adv.* **2**, e1501694 (2016).
DOI: 10.1126/sciadv.1501694
https://www.science.org/doi/10.1126/sciadv.1501694

Ringuet S, Muto F, Raymakers C. 2002. Eels: Their Harvest and Trade in Europe and Asia - TRAFFIC Bulletin Vol. 19 No. 2 (2002)
https://www.traffic.org/site/assets/files/9378/eels-their-harvest-and-trade-in-europe-and-asia.pdf

SEG. 2020. Sustainable Eel Group (SEG) position on eel stock status and our ambition for recovery - July 2020
https://www.sustainableeelgroup.org/wp-content/uploads/2020/07/SEG-position-on-the-status-of-the-eel-stock-July-2020.pdf

SEG. 2018. Quantifying the illegal trade in European glass eels (*Anguilla anguilla*): Evidences and Indicators. Sustainable Eel Group. SEG-Report:2018-1-V1
https://www.sustainableeelgroup.org/wp-content/uploads/2018/05/SEG-Report-2018-1-V2.pdf

SSC. 2021. Sargasso Sea Commission: Report of the Workshop of Range States of the American Eel, 18th-19th May 2021 via Zoom
http://www.sargassoseacommission.org/storage/documents/Final_report_-_ENGLISH.pdf

Schmidt J. 1912. The Reproduction and Spawning Places of the Fresh-Water Eel (Anguilla vulgaris), Nature 1912-08-22: Vol 89 Iss 2234 (pp 633-636)
https://archive.org/details/sim_nature-uk_1912-08-22_89_2234/page/636/mode/2up

Shepard SL. 2015. American eel biological species report. *Supplement to: Endangered and Threatened Wildlife and Plants; 12-Month Petition Finding for the American Eel (Anguilla rostrata) Docket Number FWS-HQ-ES-2015-0143*. U.S. Fish and Wildlife Service, Hadley, Massachusetts. xii +120 pages
https://www.fws.gov/northeast/americaneel/pdf/20150831_AmEel_Biological_Report_v2.pdf

Shiraishi H. 2020. Reviewing the trade in glass eels *Anguilla* spp. *TRAFFIC Bulletin* Volume 32 No. 1. 2020 - by Hiromi Shiraishi
https://www.traffic.org/site/assets/files/12779/bulletin-32-1-glass-eels.pdf

Shiraishi H, Crook V. 2015. Eel market dynamics: An analysis of Anguilla production, trade and consumption in East Asia. TRAFFIC. Tokyo, JAPAN
https://www.traffic.org/publications/reports/eel-market-dynamics-an-analysis-of-anguilla-production-trade-and-consumption-in-east-asia/

Shuo-zeng D. 2014. Eels in China: Species, Fisheries, Stock Management and Culture. 10.1007/978-4-431-54529-38.
https://www.researchgate.net/publication/299680691EelsinChinaSpeciesFisheriesStockManagementandCulture

Stein FM, Frankowski J, Nijman V, Absil C, Kranendonk I, Dekker W. 2021. Chinese eel products in EU markets imply the effectiveness of trade regulations but expose fraudulent labelling, Marine Policy, Volume 132, 2021, 104651, ISSN 0308-597X,
https://doi.org/10.1016/j.marpol.2021.104651.
https://www.sciencedirect.com/science/article/pii/S0308597X21002621

Stein FM, Nijman V. 2021. Potential increase in illegal trade in European eels following Brexit. *Oryx, 55*(3), 329-329. doi:10.1017/S0030605321000089
https://www.cambridge.org/core/journals/oryx/article/potential-increase-in-illegal-trade-in-european-eels-following-brexit/32AE3993BD79255D0FD2C84C186D9BA9

Stein FM. 2020. Success of counter glass eel trafficking in Europe is reflected by crash in European glass eel supply into Chinese eel aquaculture - Data compiled by Florian Stein, Director of Scientific Operations, Sustainable Eel Group (SEG) September 2020
https://www.sustainableeelgroup.org/wp-content/uploads/2020/09/2020-09-PRESS-BRIEF-Crash-EU-glass-eel-supply.pdf

Stein FM. 2018. The Oxford Martin Programme on Wildlife Trade: Europe's Largest Wildlife Crime: Illegal Trade of the European Eel – by Florian Stein, Director of Scientific Operations, Sustainable Eel Group (SEG) & Technische Universität Braunschweig, July 27, 2018 https://www.illegalwildlifetrade.net/2018/07/27/europes-largest-wildlife-crime-illegal-trade-of-the-european-eel/

Stein FM, Wong JCY, Sheng V, Law SWC, Schröder B, Baker D. 2016. First genetic evidence of illegal trade in endangered European eel (Anguilla anguilla) from Europe to Asia. Conservation Genetics Resources. 8. 10.1007/s12686-016-0576-1. https://link.springer.com/article/10.1007/s12686-016-0576-1

Suzuki Y, Maruyama T. 2017. Eel Anguilla japonica: Toward Zero Emission. 10.1007/978-4-431-56585-73 https://www.researchgate.net/publication/322143695EelAnguillajaponicaTowardZeroEmission

TFS. 2013. The Fish Site: Japanese Eel Aquaculture In Korea, by Banrie, 4 March 2013 https://thefishsite.com/articles/japanese-eel-aquaculture-in-korea

TFS. 2009a. The Fish Site: How to Farm Japanese Eel by Lucy Towers, November 2009 https://thefishsite.com/articles/cultured-aquatic-species-japanese-eel

TFS. 2009b. The Fish Site: How to Farm European Eel by Lucy Towers, November 2009 https://thefishsite.com/articles/cultured-aquatic-species-european-eel

TJT. 2019. The Japan Times: Fine for poaching glass eels to be raised to ¥30 million in 2023, Fisheries Agency says, October 31 2019 https://www.japantimes.co.jp/news/2019/10/31/national/japan-targets-organized-crime-300-fold-hike-top-fine-poaching-glass-eels/

TSSS. 2018. Tokyo Sustainable Seafood Symposium 2018 Report-5 - 2018.11.12 https://seafoodlegacy.com/en/7207/

Tanaka E. 2014. Stock assessment of Japanese eels using Japanese abundance indices. *Fish Sci* 80, 1129–1144 (2014). https://doi.org/10.1007/s12562-014-0807-x https://link.springer.com/article/10.1007/s12562-014-0807-x#citeas

Taylor P. 2021. Securing Industry: Major glass eel trafficking ring taken down by EU op By Phil Taylor – 7 June 2021 https://www.securingindustry.com/food-and-beverage/major-glass-eel-trafficking-ring-taken-down-by-eu-op/s104/a13544/#.YL9SYy1Q1aq

Tesch FW, Thorpe J. 2003a. Developmental Stages and Distribution of the Eel Species. In The Eel - https://doi.org/10.1002/9780470995389.ch2 https://onlinelibrary.wiley.com/doi/book/10.1002/9780470995389

Tesch FW, Thorpe J. 2003b. Post-Larval Ecology and Behaviour. In The Eel - https://doi.org/10.1002/9780470995389.ch3 https://onlinelibrary.wiley.com/doi/book/10.1002/9780470995389

Tomkiewicz J, Tybjerg L, Støttrup JG, Mcevoy F, Ravn P, Sørensen S, Lauesen P, Graver C, Munk P, Holst L, Vestbö B, Svalastoga E, Jacobsen C, Holst B, Steenfeldt S, Buelund L, Hornum T, Kofoed T. 2012. Reproduction of European Eel in Aquaculture (REEL): Consolidation and New Production Methods https://www.researchgate.net/publication/274372273ReproductionofEuropeanEelinAquacultureREELConsolidationandNewProductionMethods

Trotter B. 2021. Bangor Daily News: Millions of baby eels are caught in Maine each year, but the fish remains an enigma, by Bill Trotter - March 13, 2021 https://bangordailynews.com/2021/03/13/business/millions-of-baby-eels-are-caught-in-maine-each-year-but-the-fish-remains-an-enigma/

Tsukamoto K, Kuroki Mari, Watanabe S. 2020. Common names for all species and subspecies of the genus Anguilla. Environmental Biology of Fishes. 103. 10.1007/s10641-020-00988-3. https://www.researchgate.net/publication/342317132_Common_names_for_all_species_and_subspecies_of_the_genus_Anguilla

Tsukamoto K, Kuroki M. 2014. Eels and Humans. 10.1007/978-4-431-54529-3 https://www.researchgate.net/publication/321563055EelsandHumans

Tsukamoto K. 1992. Discovery of the spawning area for Japanese eel. *Nature* **356,** 789–791 (1992). https://doi.org/10.1038/356789a0 https://www.nature.com/articles/356789a0#citeas

Tzeng WN, Han YS, Jessop BM. 2009. Growth and habitat residence history of migrating silver American eels transplanted to Taiwan. *Am. Fish. Soc. Sym.* 58: 137–147. http://ntur.lib.ntu.edu.tw/bitstream/246246/215730/1/1025.pdf

UNEP-WCMC. 2018. Report on species/country combinations selected for review by the Animals Committee following CoP17. UNEP-WCMC, Cambridge. https://cites.org/sites/default/files/eng/com/ac/30/E-AC30-12-02-A2.pdf

UNEP-WCMC. 2015. Preliminary overview of the genus Anguilla. UNEP-WCMC, Cambridge. https://ec.europa.eu/environment/cites/pdf/reports/Preliminary%20overview%20of%20the%20genus%20Anguilla.pdf

UNODC. 2020. United Nations Office on Drugs and Crime: World Wildlife Crime Report 2020: Trafficking in Protected Species – United Nations, May 2020, ISBN: 978-92-1-148349-9 https://www.unodc.org/documents/data-and-analysis/wildlife/2020/World_Wildlife_Report_2020_9July.pdf

USDOJ. 2018. United States Department of Justice: Two Men Indicted for Illegally Trafficking American Eels – January 18, 2018
https://www.justice.gov/opa/pr/two-men-indicted-illegally-trafficking-american-eels

USFWS. 2020. US Fish and Wildlife Service: Ensuring the End of the "Eel-licit" Trade: Operation Showcases FWS' International Coordination - March 4, 2020
https://www.fws.gov/news/blog/index.cfm/2020/3/4/eels

USFWS. 2019. U.S. Fish & Wildlife Service: Operation Broken Glass
https://www.fws.gov/le/pdf/Operation-Broken-Glass.pdf

USFWS. 2015a. U.S. Fish & Wildlife Service: American eel factsheet
https://www.fws.gov/northeast/americaneel/pdf/AmericanEelfactsheet2015.pdf

USFWS. 2015b. U.S. Fish and Wildlife Service, American Eel *(Anguilla rostrata*): 12-month Petition Finding Form; Docket Number FWS-HQ-ES-2015-0143
https://www.fws.gov/northeast/americaneel/pdf/20150820AmEel12MNotWarrantedBatchFormatv2Signed.pdf

USFWS. 2007. U.S. Fish and Wildlife Service - Endangered and threatened wildlife and plants: 12–month finding on a petition to list the American Eel as threatened or endangered. Pages 72(22): 4967–4997 in. U.S. Gov't. Printing Office, Washington D.C., U.S. Office of the Federal Register
https://www.govinfo.gov/content/pkg/FR-2007-02-02/pdf/07-429.pdf

van Ginneken V, Maes G. 2005. The European eel (Anguilla anguilla, Linnaeus), its Lifecycle, Evolution and Reproduction: A Literature Review. Reviews in Fish Biology and Fisheries. 15. 367-398. 10.1007/s11160-006-0005-8
https://www.researchgate.net/publication/225950876TheEuropeaneelAnguillaanguillaLinnaeusitsLifecycleEvolutionandReproductionALiteratureReview

VoA. 2015. Voice of America (U.S. Agency for Global Media): In Northern Haiti, Conservation Efforts Focus on Coastlines **-** June 08, 2015 09:29 PM
https://www.voanews.com/americas/northern-haiti-conservation-efforts-focus-coastlines

WWF. 2021. World Wide Fund for Nature report: The World's Forgotten Fishes - 23 February 2021
https://wwf.panda.org/wwfnews/pressreleases/?1529966/Worlds-forgotten-fishes-vital-for-hundreds-of-millions-of-people-but-one-third-face-extinction-warns-new-report

Withers P. 2021. CBC News – Nova Scotia: Inside the hidden fight over Indigenous fishing for baby eels in Nova Scotia, Apr 12, 2021
https://www.cbc.ca/news/canada/nova-scotia/first-nations-fishing-baby-eels-1.5982481

Wold C. 2018. Options For Developing an Agreement Under the Convention on Migratory Species for European Eels – Prepared for the Sargasso Sea Commission
By Professor Chris Wold, Lewis & Clark Law School - UNEP/CMS/Eels2/Doc.7.1
https://www.cms.int/sites/default/files/document/cms_eels2_doc.7.1_options-for-developing-an-agreement-under-cms-for-european-eels_e_0.pdf

Young JAM, Koops MA. 2014. Recovery Potential Assessment for the American Eel (Anguilla rostrata) for eastern Canada: recovery potential assessment population modelling. DFO Can. Sci. Advis. Sec. Res. Doc. 2013/131. vi + 65 p.
http://canadianeel.org/wp-content/uploads/2014/11/Young-and-Koops.-2013.-Recovery-potential-assessment-for-American-eelpopulation-modelling.-CSAS-Res-Doc-2013131.pdf