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American Eel: A Symposium. Session One

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AMERICAN EEL: A SYMPOSIUM
SESSION ONE: SCIENCE PANEL

Moderator & Panelist:
Dr. James McCleave[1]
Panelists:
Dr. David Cairns[2]
Dr. Barry Costa-Pierce[3]

This panel covers an overview of American eel scientific research and understandings.

SCIENTIFIC OVERVIEW OF THE AMERICAN EEL FROM CANADA TO THE CARIBBEAN

James McCleave:

Good morning, everybody. I am certainly happy to be here to kick off the science side of our meeting. I am really encouraged to see people with all kinds of different backgrounds and all of us having a common interest. I am going to talk about the life history of the American eel. I am going to do it "mythbusters" style . . . .

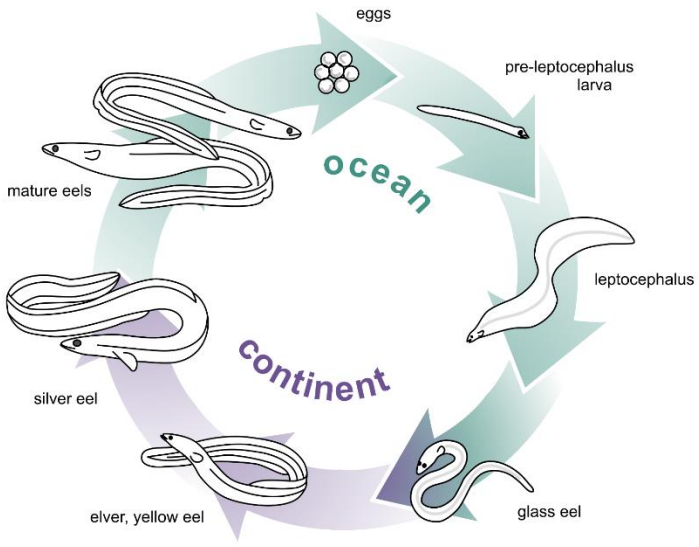

Figure 1. Eel Life Cycle.

In a nutshell, spawning of the European and American eel occurs in the Sargasso Sea; we all know that already. Eggs hatch in a couple of days, and the larvae called leptocephali drift on ocean currents for a year, or a year and some months, in the case of the American eel.

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When those larvae approach the continental shelf, somewhere along there they metamorphose into glass eels which are more eel shaped but without pigment. Those are the glass eels at the stage that enters our coastal waters, our brackish waters, and fresh waters. They develop pigment and have a growth phase in those continental waters that lasts several years depending on environmental conditions.

At maturity, the silver eels migrate back to the Sargasso [Sea], spawn and die. So it is a one shot deal.

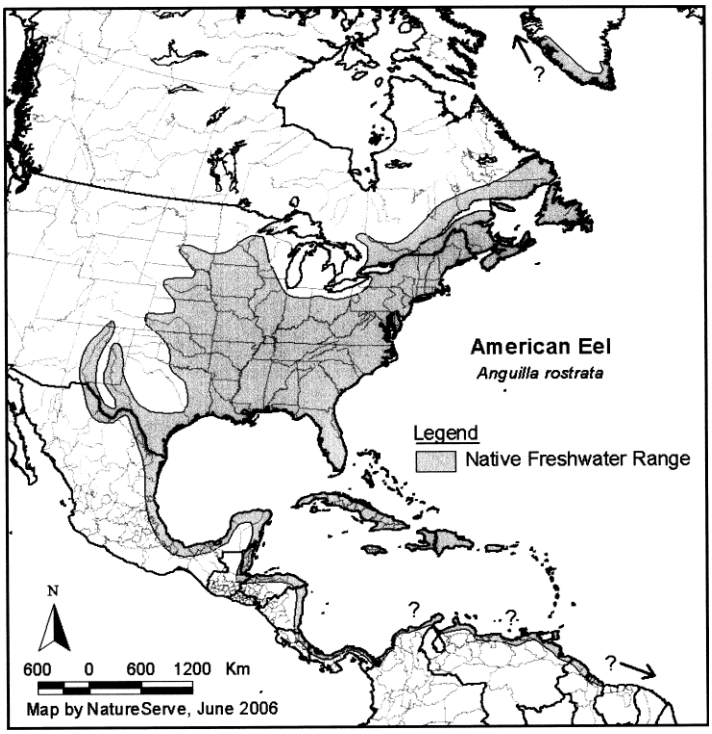

Figure 2. Distribution of American Eel in Freshwater.

I have put a map up . . . of [approximately] what was the historical distribution of the American eel, [showing] penetration well up the Mississippi drainage and so on. I am sure that map is quite shrunk at this point but just to give you a historical perspective.

So, how do we know that eels spawn in the Sargasso Sea? Spawning eels have never been seen there . . . . So we know that they spawn in the Sargasso by the distribution of the smallest of the larvae.

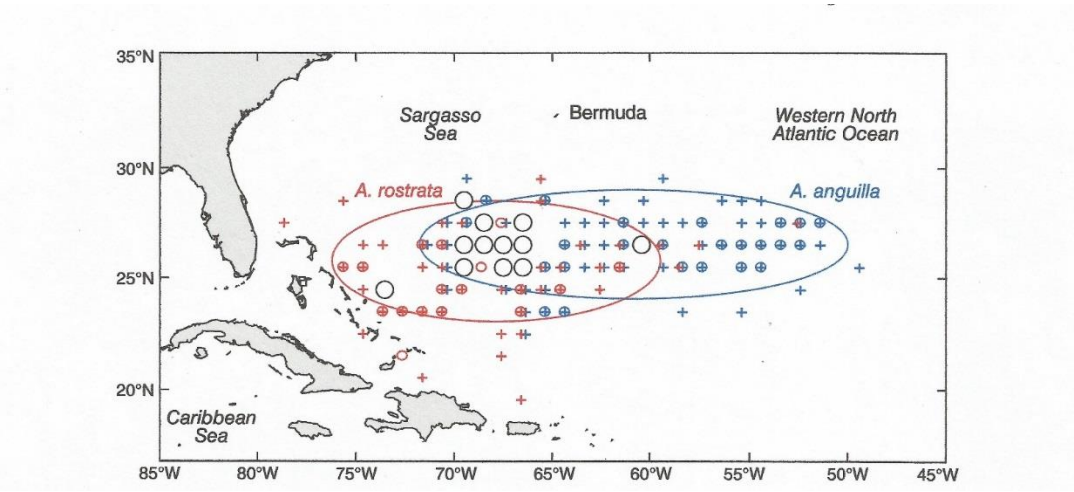

Figure 3. Locations of American Eel Collection.[4]

[Figure 3], from a large database, shows in red symbols, where leptocephali of the American eel, 11 millimeters or less in length, have been captured. The blue symbols show the same thing for the European eel. The large circles, show where leptocephali less than or equal to 6 millimeters in length, of both species, have been captured in the same net tow, to give you an idea of the spatial and temporal overlap of spawning of the two. I think we can confirm that eels spawn in the Sargasso [and know] from the distribution of larger leptocephali that [the Sargasso] is the only spawning location.

One of the key questions in my mind is, as those leptocephali approach continental waters, how do they get out of the current systems and onto the continental shelf so that they can penetrate into fresh waters? The recent suggestion is that there may be some oriented swimming by these larger leptocephali. I do not know, we do not have any good evidence one way or another. Let's just call it a plausible hypothesis that at some point behavior comes into play.

Anguilla [species] were long thought to be the quintessential catadromous species, that is being born in the ocean and migrating into fresh water for a growth phase. It turns out that is not quite the story. From microchemistry studies, based on the idea that the strontium to calcium ratio is higher in sea water than it is in fresh water, we have a mechanism for tracing the salinity history of a large eel back through its life by looking at the ratio of strontium to calcium in the ear stones, the otoliths, of eels. One can look from the core to the periphery and get an idea of the salinity history.

I will just say overwhelming evidence shows that there are many life history patterns in eels, and I will show you some quickly.

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[4] MICHAEL J. MILLER ET AL. (2015). Locations where small larvae 3.0-5.9 mm (small circles) and 6.0-10.9 mm (crosses) of *Anguilla rostrata* (red symbols) and *Anguilla anguilla* (blue symbols) were collected, pooled into 1 degree areas. Large circles show areas where <6 mm-long larvae of both species were collected. Ovals show estimates of the primary spawning regions of the two species.

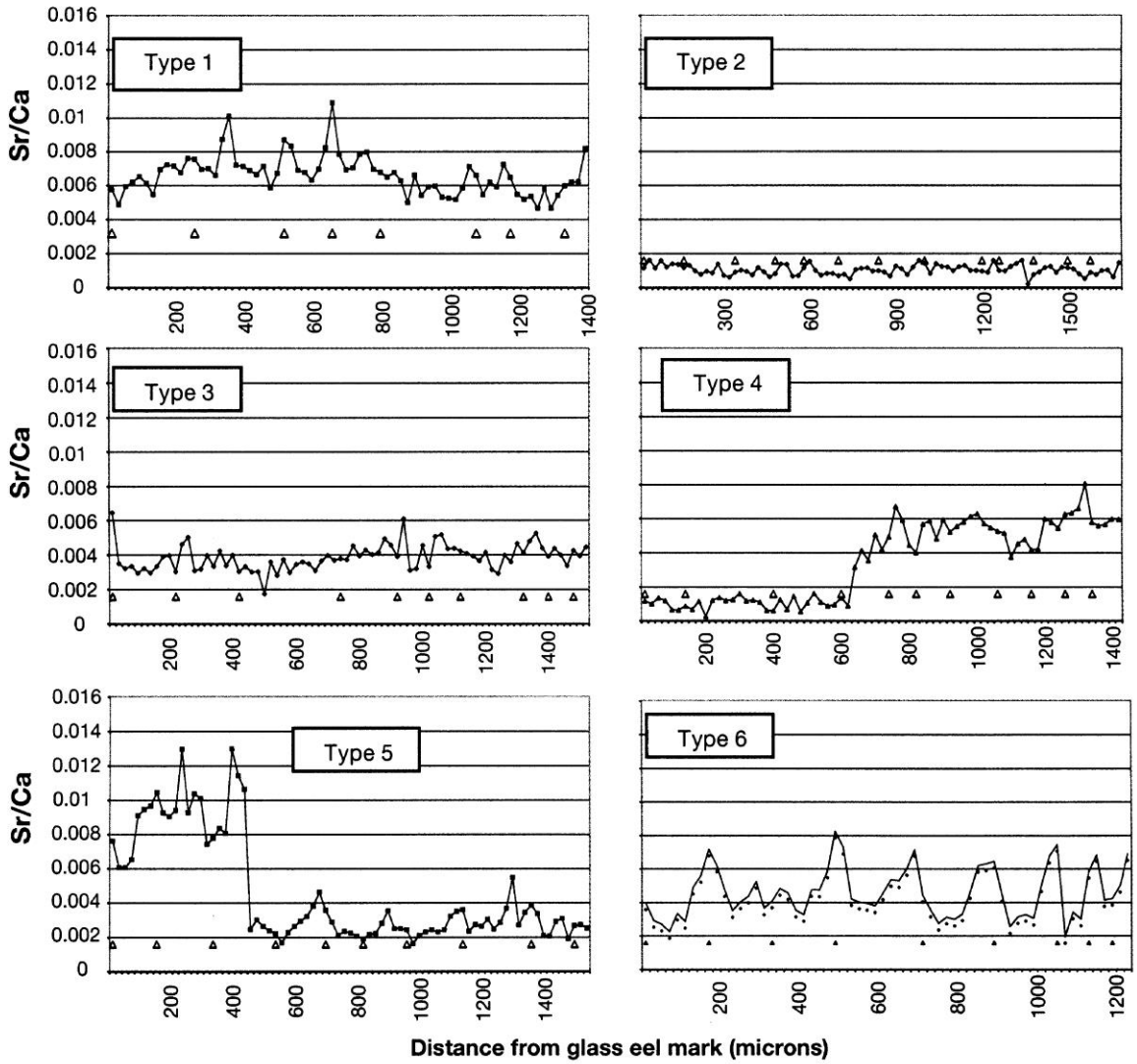

Figure 4. Strontium to Calcium Ratio of Various Eels.[5]

[Type 2] would be the classic, it is a 13 year old European eel in this case, so after the glass eel stage, that is the strontium to calcium ratio over those 13 years. That fish was in fresh water with a very low ratio of strontium to calcium for its whole life cycle. But there are lots of other types. Some that never come into fresh water (type 1); some that come into estuaries with intermediate salinities (type 3); some spend some time in . . . fresh water [and then return to coastal waters] (type 4); some do the opposite (type 5); and some go back and forth (type 6). We have evidence essentially in all of the temperate species that these patterns all exist.

I think the idea that these are strictly catadromous is a busted hypothesis. Catadromy is facultative and one of the things we do not know very much about is the extent of . . . the marine component.

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[5] F. DAVERAT ET AL., TRACKING CONTINENTAL HABITAT SHIFTS OF EELS USING OTOLITH SR/CA RATIOS: VALIDATION AND APPLICATION TO THE COASTAL, ESTUARINE, AND RIVERINE EELS OF THE GIRONDE-GARONNE-DORDOGNE WATERSHED (2005).

Scientists are always good at calling for more research, and I am sure we will make some calls this weekend. But here are a few that are based on what I have just outlined as the life cycle. What is the extent of the marine habitat use? It is very hard to sample there. What determines the settlement of glass eels? And what determines later movements? We do not really know the whole story, but it could be related to physiological status of glass eels, competition among individuals, competition for food supply, genetic predispositions to settle in some location or another. Those are all plausible hypotheses but they are areas for considerably more research.

We could ask the question why catadromy persists in temperate zone eels, and I am drawing on work by my colleague who is going to speak next, David Cairns, who asked that question in a publication. In temperate regions, the coastal oceans are more productive than fresh water, so one might expect eels to remain in coastal waters for better food supply and so on. But Cairns and colleagues suggested that diverse habitat use might reduce the variance in fitness of the population whereby some individuals actually have greater genetic fitness by being in fresh water than in salt water. Again, I think a plausible hypothesis that needs additional research.

Next, [a] controversial [concept], but very important to our considerations this weekend, is whether eels are panmictic populations or not. Panmixia is a state in which a species exists as one, randomly mating population for the entire species. So, a female from Maine could mate with a male from Costa Rica or [Newfoundland].

There was early work that argued that the North Atlantic eels are not panmictic, and those studies I think are flawed for reasons based on advances in our [genetic techniques and] knowledge. . . . I am not going to dwell on [the point].

Recent work has [clearly] confirmed that the European eel, the American eel, the Japanese eel are all panmictic species. That evidence comes, to make a long story short, from studies that have examined what are called neutral genetic markers [which] are little snippets of DNA in the eels that do not code for anything. Therefore, they are not subject to natural selection. That way, if it is a panmictic population, those snippets should look like the same distribution anywhere you go. There is no evidence for genetic structure of these neutral markers in any of those species. And, at this point people have looked at American glass eels, European glass eels, yellow eels, silver eels. There have even been analyses of leptocephali captured in the Sargasso Sea and there is no indication in those markers that there is anything other than [panmixia in each species].

One of the important points of panmixia, why it is important, is it gives a species with a complex life history, a very large geographic range, an unpredictable larval transport, the opportunity to thrive under a variety of environmental conditions. Hence, we see thriving populations in tropical waters all the way up to subarctic waters. One more point on panmixia is in [an eel] species many age classes spawn in any given year because of differences in how quickly they become silver eels in warm waters versus cold waters. [Those] multiple age classes spawning gives further indication [that each] breeding year is putting back genes that were there in multiple years previously. I think that just reinforces the idea that panmixia is not just an instantaneous event, it is an ongoing event.

Variations in responses to various environmental conditions – what we call plasticity – can arise phenotypically or genotypically. I am not going to talk about phenotypic variations, it is just whatever the environment does to me, it makes me grow a little bit, or not grow a little bit, or get gray hair or whatever. But I want to consider the question: does panmixia, which is [the product

of] random mating process, mean that each individual is genetically identical? And no, it does not mean that. It means that each individual in a generation receives some random component of the genetic variation that is present in that breeding population. So individuals, leptocephali, in this case drifting on the ocean, are not all the same. They have got subtle differences. And that means they could be selected [for or against] by natural selection depending on the environmental conditions that are encountered during that drifting period. And, again, to . . . draw on some work of my Canadian colleagues, Gagnaire and [coworkers] found a significant genetic variation in glass eels collected at 17 different locations from Florida to Newfoundland, and found that there are a number of loci, little snippets of DNA now that code for proteins or code for certain behaviors and so on, are different along that geographic range, and some of those are correlated with temperature or latitude which co-vary.

Côté and colleagues, also in Canada . . . captured glass eels from Cape Breton Island and the lower Gaspe Peninsula, . . . brought them into the laboratory, raised groups from each location in fresh water and in brackish water for three months, and then looked at their genetic structure. And they found that more than 100 loci, little spots on the DNA, that show variation related to location or rearing conditions or some interaction of both. And these snippets coded for known proteins or behavioral aspects, or structural aspects, or whatever, and those hundred-and-some fell into functional groups of genes. We do not know exactly what that means, but I think we are on the verge of a real advance in knowledge to begin to understand what natural selection has occurred in relation to environmental factors that are acted upon, the genetic components primarily at the leptocephalus stage. But, [that advance will come when we] learn what the difference is between the genetic structure in this category of genes and what it means in terms of who ends up in Quebec and who ends up in South Carolina.

Finally, Pavey and colleagues collected older eels, yellow eels, from [several] different locations in the Maritimes, some in fresh water and some in brackish water, . . . looked at the genetic component, and found three hundred-and-some loci that varied among those 16 collection locations. Some of the genes are fixed for the fresh water component, some are fixed for the brackish water component, and others just varied among the locations. [There were] quite distinct differences in the genetic structure of those older eels in the [brackish or fresh waters] from which they came.

These results all show what we call spatially varying selection, and again, probably what occurs at the leptocephalus stage. So back to the point of how important the Sargasso Sea is. I think we can confirm that even though we have panmixia, we still have the opportunity for genetic differentiation among individuals that are growing in different waters.

Because of panmixia we might postulate that human influences are not important, but I want to make three [points] about that. I could make [the whole subject a] seminar, but let's just say that works done in Canada, [have advanced our knowledge] in a number of [pertinent] aspects. Over several years, scientists in Canada collected glass eels from several rivers in New Brunswick and Nova Scotia, and transplanted those glass eels into the Richelieu River which drains Lake Champlain, the upper Saint Lawrence River, and Lake Ontario. These are all locations where the naturally occurring American Eels have experienced an extreme decline, so the hope was that transplanting the glass eels would let those grow to large size like the [female] eels that left Lake Ontario historically. Again, just the essential results, some of those stocked eels turned into males;

[there had] never been males reported in the upper Saint Lawrence and Lake Ontario region previously. There is some indication that the sex ratio of those transplanted eels does not mirror the sex ratios of eels that naturally recruited to the upper Saint Lawrence. Growth rates tended to be high in the stocked eels, but they matured at a very much shorter size, and therefore very much less fecund size.

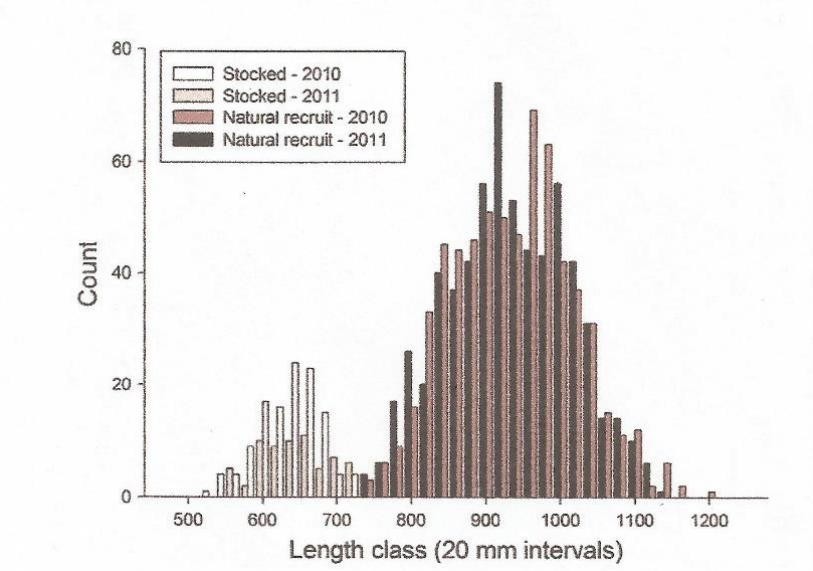

Figure 5. Count and Length of Silver Eels Caught in Commercial Fishery.[6]

Here are some examples of stocked eels in the light colors, and naturally recruited eels in the dark bars. These are individuals migrating to sea that were captured in a commercial fishery in the lower Saint Lawrence, and you can see there is quite a difference between the two. In other words, the glass eels transported, retained characteristics that were present in the glass eels at the location they were captured. They did not become Saint Lawrence eels, if you will.

If that translocation gives us [small] eels we can ask the question, [one,] do they have enough energetic stores to migrate all the way to the Sargasso? And, two, what is the fecundity of those compared to the fecundity of the much larger eels? Fecundity [increases] exponentially with body size.

[The conclusion] in a recent paper by Stacey and colleagues who conducted some of those experiments, sums up what we know so far:

> These results provide a warning about the use of conservation stocking as a panacea for declining recruitment in North Atlantic eels… [and]… do not support the contention that eels will take on the life history traits of naturally recruiting eels to the same water body. We question whether the translocation of eels from different geographic locations… is an effective conservation measure for American eels.[7]

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[6] JOSHUA A. STACEY ET AL., A CAUTION FOR CONSERVATION STOCKING AS AN APPROACH FOR RECOVERING ATLANTIC EELS (2014).
[7] *Id.*

I am going to put a tentative "busted" up there. Some of you might argue with me. [However,] there is [considerable] literature on the European eel [reporting] translocation experiments [conducted over] decades. [Those results] also show that things [frequently] do not turn out the way that one would like them to turn out.

We have already seen that the sex ratio of American eels in the Saint Lawrence basin has been altered by stocking. I could give you examples from New Zealand, examples from Europe and Japan, back up the idea that transplanting eels does not automatically make them have the same life history characteristics that would typically occur in that region. I think we have confirmed that that the sex ratio can be changed by these stocking experiments and not particularly in ways that we want. The usual pattern is the change from a female dominated system to a male dominated system which does not do us any good in terms of eel reproduction.

The final point I want to make in this section of my talk is: can oceanic changes in the North Atlantic alter recruitment patterns and abundance? One of the measures that serves as a proxy for [many] processes that go on in the North Atlantic is the North Atlantic oscillation, which is the sea level atmospheric pressure difference between the Icelandic low system and the Azores high system. It fluctuates from time to time, sometimes randomly, sometimes in a pattern.

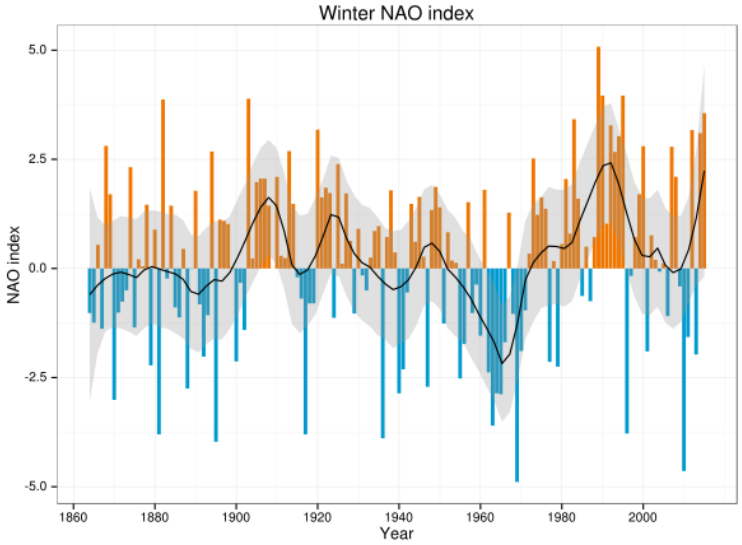

Figure 6. Winter North Atlantic Oscillation Index.

The index of the North Atlantic oscillation since 1860 or so [is shown in Figure 6]. It is a very messy kind of pattern, except that you can see [in recent times a] period of a decade or two in which the index [was] negative, followed by a rather abrupt change to a lengthy period in which the NAO [was in] a positive state.

Why am I telling you all this? There is a recruitment index for glass eels at one location in the Netherlands that has been in place since the 1930s. It is called the Den Oever Index. Den Oever is where the [glass] eels are sampled. They got sampled every spring except war years [and sampling continues].

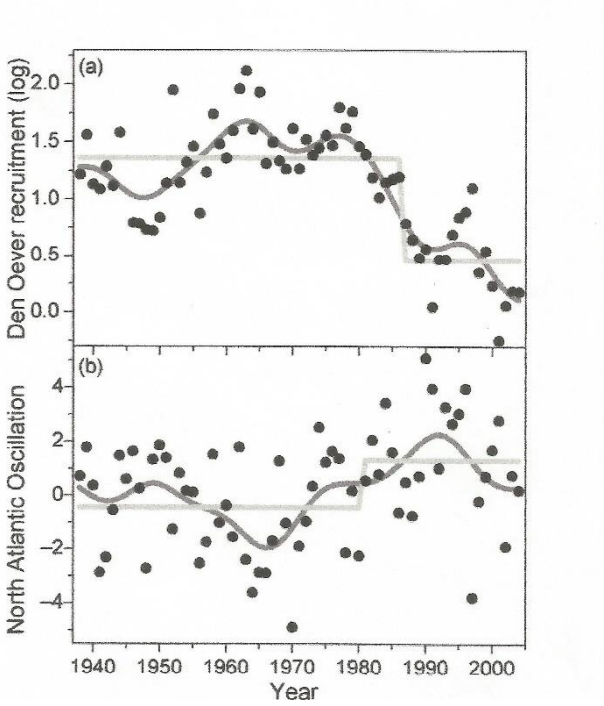

Figure 7. North Atlantic Oscillation and Den Oever Index Correlation.

[Figure 7 top panel shows what the index looked like. The index] is variable but you can see its high recruitment in the early part of the time series and then a very rapid decline.

The bottom panel shows the North Atlantic Oscillation Index and over the same time period there is an inverse correlation between the two [indices]. The correlation does not necessarily mean causation, but there is a correlation between the two about -0.4 with a 1 or 2 year lag, the time it would take leptocephali to cross the Atlantic. Given the messiness of both of those data series, the correlation coefficient of about 0.4 strikes me as pretty solid.

The North Atlantic Oscillation, or that pressure difference, influences all kinds of processes in the North Atlantic in the air, on land and, especially for eels, at sea. Sea surface temperatures change, mixing depths change, current patterns change, the strength of gyres around the Sargasso change in response to the fluctuations in the North Atlantic Oscillation Index.

[Here are two] examples that were published in the paper by Friedland *et al.* that don't necessarily prove that there is a connection between the two but offer us several hypotheses for how the North Atlantic Oscillation can influence the processes that affect eels during the time of their larval growth. Over the last several decades, they point out that Ekman transport has weakened in the North Atlantic. Ekman transport is wind driven surface currents and because of the prevailing winds, the water transport tends to move from the north to the south and from the south to the north into a convergence zone, which is where surface temperature changes rapidly. That is the area where American eels and European eels spawn. There is a connection somehow between that convergence zone and spawning.

So if Ekman transport has weakened in recent decades, especially the transport from the north into the convergence zone, does that mean that eels have had a harder time finding mates because the convergence zone is not as distinct as it was a few decades ago? One point.

Second point is that those wind driven currents, affect the westward drift from the Sargasso into the Gulf Stream system. And if those currents have weakened, does that mean leptocephali have been less successful at getting out of the Sargasso? I do not know. That is the hypothesis.

The [third point], which is again just a hypothesis, but we believe leptocephali feed on detritus – dead, organic matter that comes from fecal pellets or bodies of zooplankton that gradually sink and collect bacteria that the leptocephali eat. So if Ekman transport has weakened, this means the surface mixing layer has become shallower, and this means that nutrients are not able to get into the productive surface water as well as in a deeper system. So we could hypothesize that maybe those effects of the North Atlantic Oscillation on just surface currents in and around the Sargasso have the possibility of multiple effects that all could be negative for the eels. We can say that it is pretty certain that there are effects, more than just the ones I mentioned that are very plausible, but the direct links at this point between some effect of the North Atlantic Oscillation on specific eel year classes is not yet demonstrated.

I do not know how to make a transition to the last points that I want to make. Now for something completely different. I think it is important in the context of our Canadian and U.S. meeting here that we consider the range of the American eel in the wider Caribbean. My colleague, José Benchetrit, and I just published a paper on this subject this year.

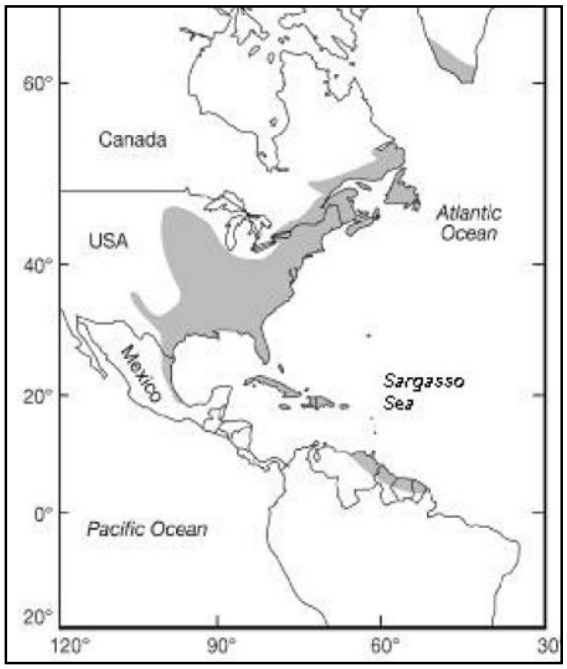

Figure 8. Range Map of American Eel.[8]

[8] COSEWIC STATUS REPORT (2012).

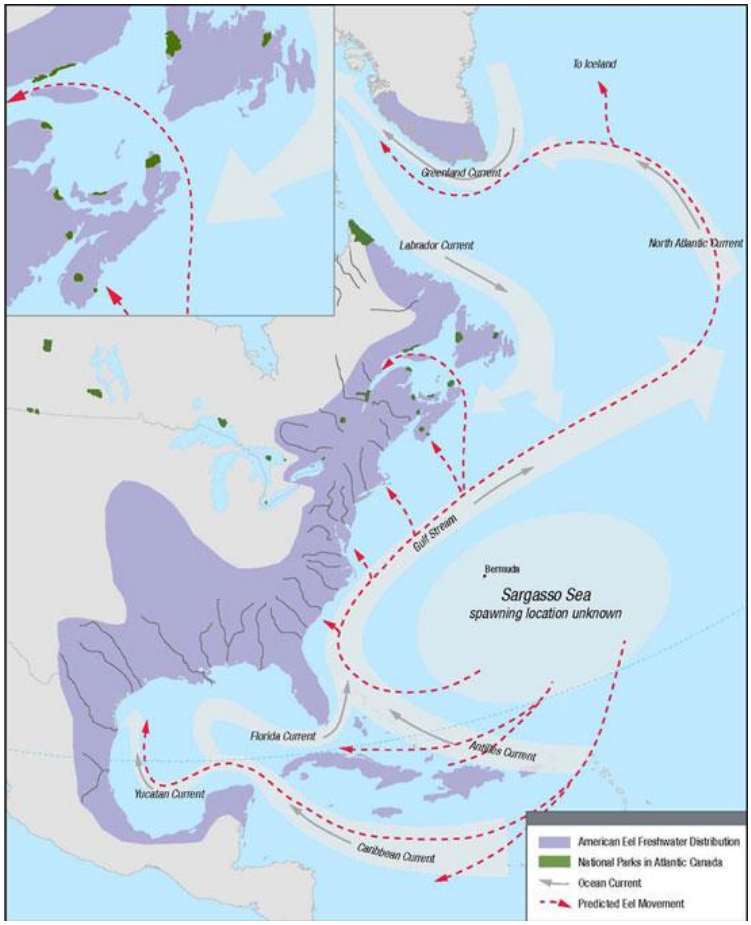

Figure 9. Range Map of American Eel.[9]

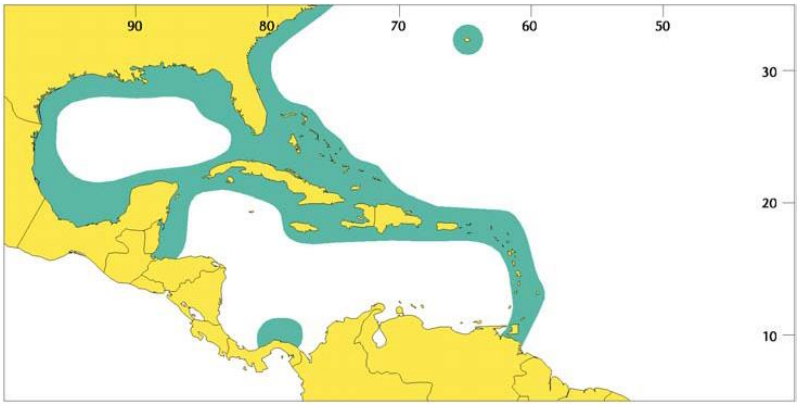

Figure 10. Range Map of American Eel.[10]

[Figures 8, 9, and 10] are some recent range maps for the American eel, published pretty recently. I just want to say at the outset that all three of them are incorrect in the southern part for various reasons. Given that, we decided we would try to [determine] what is really [the situation]

[9] Species at Risk: The American Eel, PARKS CANADA, http://www.pc.gc.ca/eng/nature/eep-sar/itm3/eep-sar3aa/1.aspx.
[10] SMITH (1989).

down there. Not very much known in the literature on the American eel in the tropical part of its range. We set out to document the current and historical distribution of the American eel in the tropical part of its range. And secondly, to give a preliminary examination of potential threats to American eels in that part of the range. This was a desktop study; we looked at museum records, we looked at published primary and secondary literature, we made contacts with curators at museums, with local scientists, with fisheries personnel, [we sought] information people like Mitch [Feigenbaum], who helped us out. We did not get much help from government officials or fishery officials from the region. [However,] we did the best we could.

Figure 11. Wider Caribbean Range of the Benchetrit & McCleave Study.[11]

The domain we considered [ranged] from Mexico down through Central America across the northern part of South America and all of the Caribbean islands (Figure 11). We found historical and current records of American eels [generally] anywhere through the region where there are permanent, fresh water, river systems. Some of the Caribbean islands that are volcanic do not have any permanent, fresh water, and therefore do not have eel populations. There were numerous records that we uncovered from Martinique, Puerto Rico, Honduras, Panama Venezuela, and I should probably say Costa Rica as well. They are based on [reasonably] good records from people who were there to survey for eels among other things. There are no records from Guyana southward that show on some of those earlier maps . . . . The Orinoco River, a very big system, flows into the Atlantic Ocean on the eastern part of Venezuela. There are no eels in it, and it has been intensively studied for its fish fauna. [Two specimens purportedly] from French Guyana . . . were deposited in the Museum of Natural History in Paris, [but they] turned out to be leptocephali.

[11] Benchetrit & McCleave, *Current and Historical Distribution of the American eel,* Anguilla rostrata, *in the Countries and Territories of the Wider Caribbean*, ICES JOURNAL OF MARINE SCIENCE (2015).

They were caught at sea and they were not in coastal waters at all. So we are pretty sure that southern limit of distribution is eastern Venezuela and Trinidad & Tobago.

We also found published literature on the negative effects of hydroelectric and other dams, and water abstraction in some locations, particularly on the islands of Guadalupe and Puerto Rico where scientific studies have been undertaken. There are also threats to local stock from proposed dams in Panama and in Costa Rica, in areas that are now national parks and are conserved from development. If those dams go in, we have another unfortunate situation. There is also evidence that pollution has altered the distribution of American eels in some places such as Trinidad. There has been a development of a commercial fishery for glass eels in the Dominican Republic and maybe clandestinely in Haiti, as well as a few other locations down there.

American eels are historically and currently present through most of the Caribbean, and in Central, North and South American regions that have good fresh water systems. Eastern Venezuela and Trinidad & Tobago are the southern limit; we are confident about that conclusion. There is developing pressure from glass eel fisheries in the region, and there is habitat loss and degradation that are important threats to the American eel in the Caribbean region.

A point for our meeting here is that because of panmixia, effective international efforts to manage the species must take into account what goes on in the Caribbean, and we need to engage with scientists and policy people in the Caribbean and bring them into the picture so that we can get a species-wide examination of what we are trying to accomplish in the northern part of this region.

I have gone through a lot in a hurry. You might want to take some of it with a grain of salt, because I have in the past been described as mentally eel. Thank you very much.

At this [time], we will make a transition to my friend and colleague from Canada, PEI, David Cairns.

DISTRIBUTION, BIOLOGY, AND CONSERVATION OF AMERICAN EELS IN CANADA AND NORTH OF CANADA

David Cairns:

For an eel biologist, the idea that we need an international governance system that matches the geographic distribution of this widely [and] internationally distributed panmictic species, is a matter of simple and incontrovertible logic. Some of us in the biological community have been pushing internally within our governments in this direction without visible results, so I would like to say that I am personally delighted that this meeting is happening, and I would like to thank and congratulate those who brought it together. I hope we will, indeed, see progress in creation of a governance system for the American eel that matches the species' conservation needs.

I will be talking about biology of the American eel in Canadian waters. I will also be talking about the interface between biology and management.

Panmixia and stocks: Jim [McCleave] went through the whole panmixia issue in some level of detail but certainly not in the entire level of detail because panmixia has become this giant, complex issue, that is going to make the careers of a number of eel scientists . . . because it is so complicated. Every paper finds new things to dig into.

But those of us who are not geneticists tend to think of panmixia as a very simple thing; we tend to think of it as a matter of some degree of uniformity in the genome across a broad geographic area, in fact across the entire species range. If that were the case, our job as eel biologists would be much simpler because eels would be a fairly uniform species in their biology. Their life history characteristics and so on would be rather uniform over this large range.

This is, in fact, not the case. Panmixia, the idea of uniformity of the genotype, occurs only immediately after the hatching of these larvae in the Sargasso Sea. As soon as they begin to distribute themselves across their continental range, the genetic similarity, or homogeneity, breaks down [with] spatially varying selection, and they are no longer genetically homogenous. It is an odd kind of system where genetic homogeneity is created with each generation, it is lost within the generation, and [in] the next generation it is created again.

But we who fish eels and study eels largely work in continental waters. In those locations where we as humans interact with eels, the genetics of the species are spatially highly variable, highly heterogeneous. So, the paradox of panmixia is that a genetic system that could potentially or theoretically deliver a simplifying element to make our jobs easier, in fact makes them much more complicated.

The nature of eels varies because of their spatially varying genotype . . . , but also because the species itself it enormously plastic. It responds to environmental pressures to produce different kinds of life histories, different sex ratios, different growth rates, and many other features. So when you have a species that is so variable in how it lives, and where it lives, and what it does, it makes the job of understanding how biology interacts with management much more complex.

Eel range within Canada:

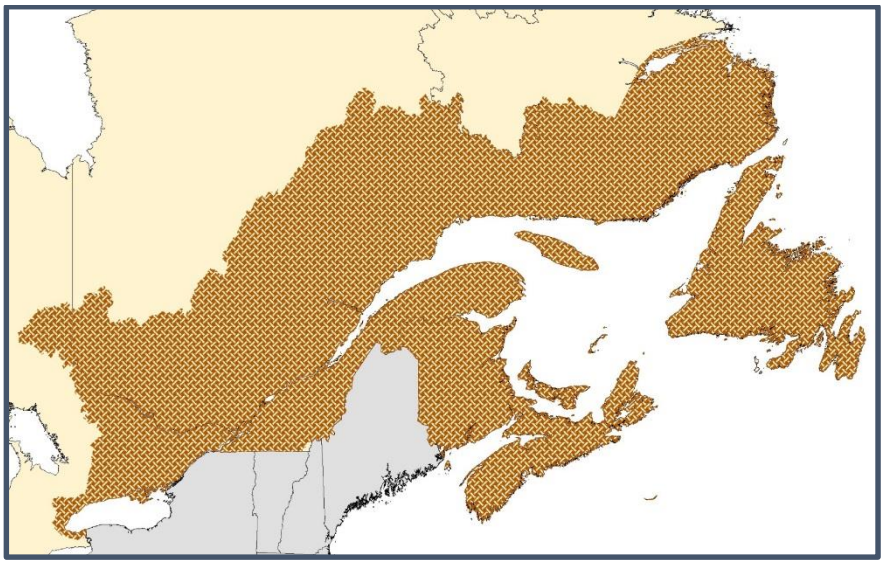

Figure 12. Canadian watersheds, below Niagara Falls, that flow into the Atlantic Ocean.

[Figure 12] is a map of the watersheds . . . that flow into the Atlantic Ocean from eastern Canada, from Lake Melville in Labrador up to Niagara Falls in the Saint Lawrence system. The original range of the American eel in Canada probably approximated what you see in this map. Eels are enormously capable and adept at going upstream, past obstacles, even quite substantial waterfalls

and rapids. They can find their way, especially at an early, small stage, by slithering around rocks and creeping along wet areas close to the water course to find their way upstream. In the modern era of large, concrete dams, that becomes more difficult. There is also a small range of the American eel in Greenland. They are present in Greenland, but populations are probably quite low. [The] biology and distribution of eels in Greenland is not well-studied.

The range [in Canada] includes both saline (salt and brackish) waters and fresh water. On the saline side in Canada, we have an estimate of about 9,000 square kilometers of habitat which is suitable for eels, and which is probably occupied by eels. Fresh water is probably a larger number than that, but it has not been measured. In the U.S., [there are about] 14,000 square kilometers of saline water habitat [and] 18,000 square kilometers of fresh water habitat. [However,] . . . a good portion, but an unknown portion, of [fresh water habitat] is not accessible [to eels] due to dams and in some cases, natural obstructions.

The range in fresh water has diminished, especially in areas that are distant from the sea. In Canada, the . . . area [where this] has been [most] thoroughly investigated is Ontario.

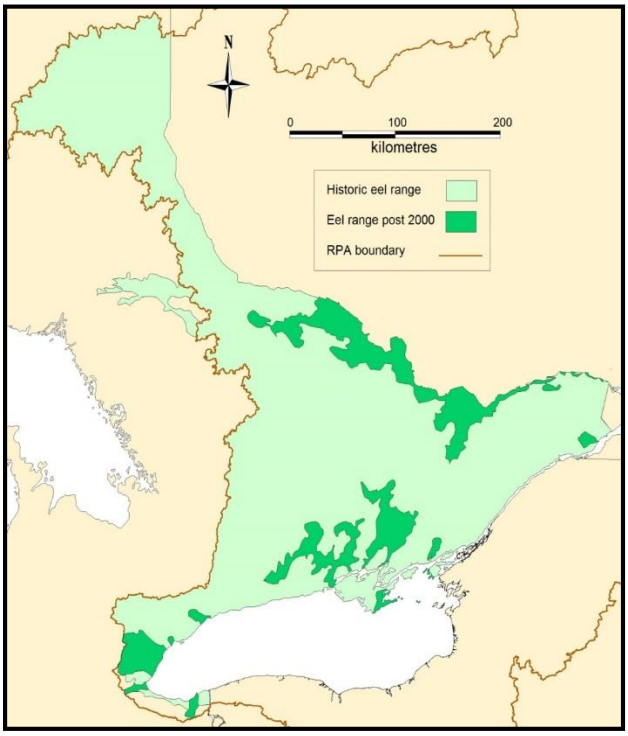

Figure 13. Eel Range in Ontario.[12]

The [historic] range, in pale green, . . . based on quite an extensive examination of records, [shows that a widespread distribution. The dark green shows distribution since 2000.] You can see a very marked range of constriction in the province of Ontario.

[Commercial] eel landings . . . in Canada peaked in the 1930s, went down in the 1940s and 1950s, climbed up again in the 1970s and 1980s, and since the late 1980s there has been a pronounced decline by about two-thirds.

[12] ROB MACGREGOR ET AL. (2010).

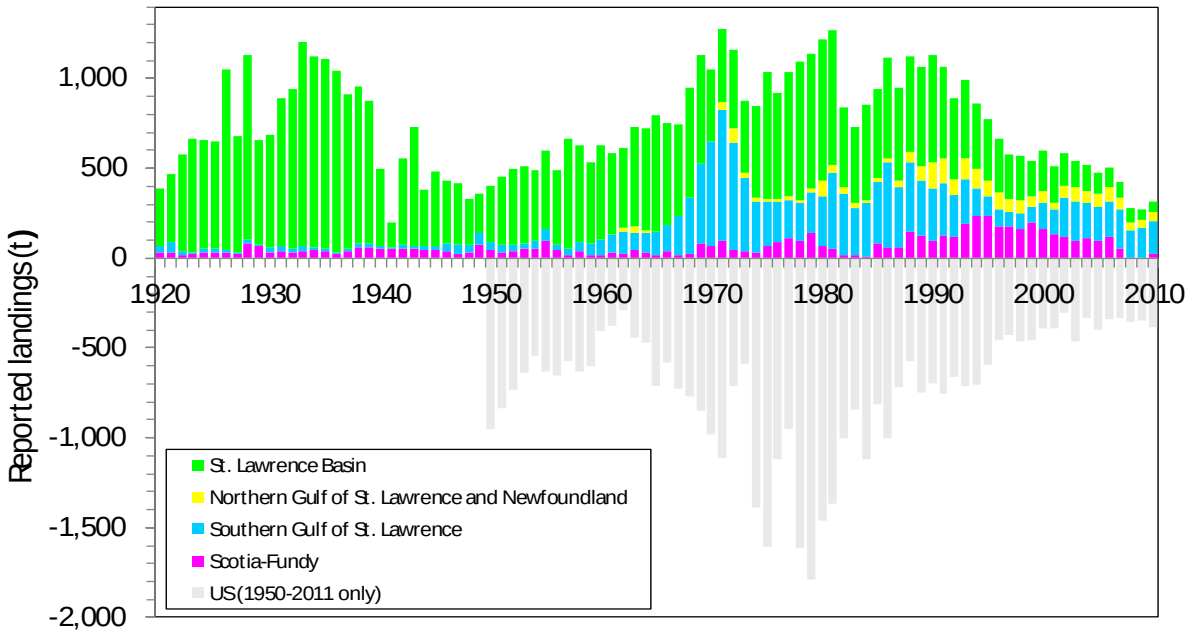

Figure 14. Eel Landings in Canada.

[In Figure 14,] the gray bars represent U.S. landings. You can see that these Canadian and U.S. landing patterns are broadly parallel, almost symmetrical. As Canadian landings have declined, U.S. landings have declined in a similar way.

A couple of things to note about the Canadian eel fishery. In the past 20 or more years, there have been two major shifts, one in terms of the major fishing area, in terms of tonnage of eels. The traditional location for the largest eel fishery in Canada has been the St. Lawrence River and a part of Lake Ontario. The center of gravity, if you will, of the Canadian eel fishery in terms of tonnage has shifted from there to the southern gulf of the St. Lawrence, and in terms of dollar value, the shift has moved towards what we call the Scotia-Fundy area, [which is the Atlantic and Fundy coasts] Nova Scotia and New Brunswick. Landed values for the yellow and silver component of Canadian fishery are ballpark $5,000,000 a year. That is not a large sum when you consider other fisheries that exist in Canada, [with] hundreds of millions of dollars in value. The elver fishery over the past number of years has emerged as by far the major portion of the economic output of the eel fishery in Canada, with landed values of several tens of millions of dollars.

One thing that has not changed is that the focus of conservation concern in Canada remains the St. Lawrence River axis. The American eel was formerly very important in Lake Ontario. At one point, it was the second largest commercial fishery in Lake Ontario. There was also a very large and culturally quite significant fishery in Quebec, in the St. Lawrence River itself. That fishery has diminished to a very large extent. And because of the declines in population in the St. Lawrence system, and the longstanding cultural and economic importance, there is a very high degree of concern about American eel conservation in that area. In the Atlantic provinces, quite frankly, there is much less conservation concern because as we will see, the drastic decrease in eel abundance that has been seen in the St. Lawrence has not yet occurred in the Atlantic provinces.

The status of the American eel in Canada has been reviewed a number of times. We have a body in Canada called COSEWIC (Committee on the Status of Endangered Wildlife in Canada**)** which is a scientific body, which reviews species at risk in the country. In 2006, it examined the case of the American eel and classified it as Special Concern in Canada. The Ontario government has its own classification system, and called the American eel Endangered. COSEWIC came back to the American eel in 2012, and this time it called it Threatened. And finally, the IUCN (International Union for the Conservation of Nature) did a review of the American eel across its range including Canada, and that classification came out as Endangered. On the U.S. side, the U.S. Fish & Wildlife Service, acting for the Endangered Species Act, examined the case of the American eel in 2007, and it decided that it would not fit in any of the existing categories. The Atlantic States Marine Fisheries Commission did an assessment of the American eel in 2012 and called it Depleted. The U.S. Fish & Wildlife Service came back in 2015 and it also gave it a no category classification. I should point out that the American and Canadian classification systems differ in that on the Canadian side of the border we have a classification called "Special Concern" which is lower than "Threatened." ["Special Concern"] does not exist in the U.S. side. One might speculate, and it would only be speculation, that if the "Special Concern" category [existed] in the U.S. system, then perhaps the American eel in the U.S. might fall into that category.

In Canada, there is a distinction between assessments by COSEWIC, which is an assessing body, and the official listing by the government under the Species at Risk Act. A study recently came out in the Canadian Journal of Fisheries and Aquatic Sciences which reviewed the outcomes of species at risk assessments by COSEWIC in marine fish and it found that the most common outcomes were that after COSEWIC assessment, there were delays of a number of years, before . . . an official listing decision made. In other words, the species was just there, sitting on a shelf, in limbo, until a listing decision was made. And the other common outcome was that COSEWIC recommendations for Threatened and Endangered status were not accepted and the species was not officially listed. In the case of the American eel, COSEWIC first assessed the American eel in Canada in 2006, and nine years later the government of Canada has still not made a decision on that or the subsequent COSEWIC assessment in 2012 as to whether or not this species will be listed in Canada.

The Canadian status was examined by COSEWIC in 2012 but there has been a more recent review of status. . . . In the upper St. Lawrence River there is a longstanding index at a major hydrodam, called Moses-Saunders Dam. That index declined precipitously in the 1980s and 1990s. There has been a slight improvement recently, but still the numbers are a very small fraction of what they were 30 and 40 years ago.

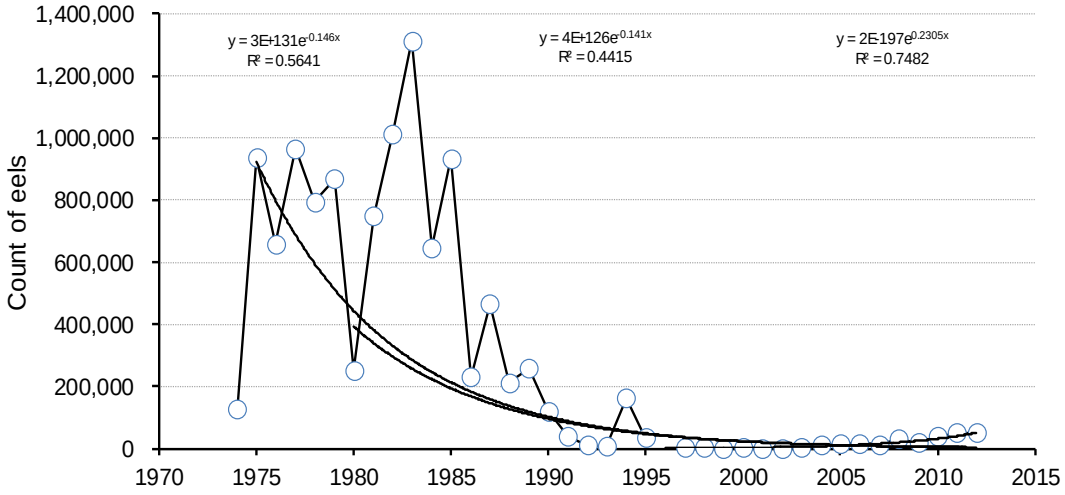

Figure 15. Precipitous Decline of Eels in the Upper St. Lawrence River.

So [Figure 15] is one end of the scale; this is sort of the worst case of what happened in Canada.

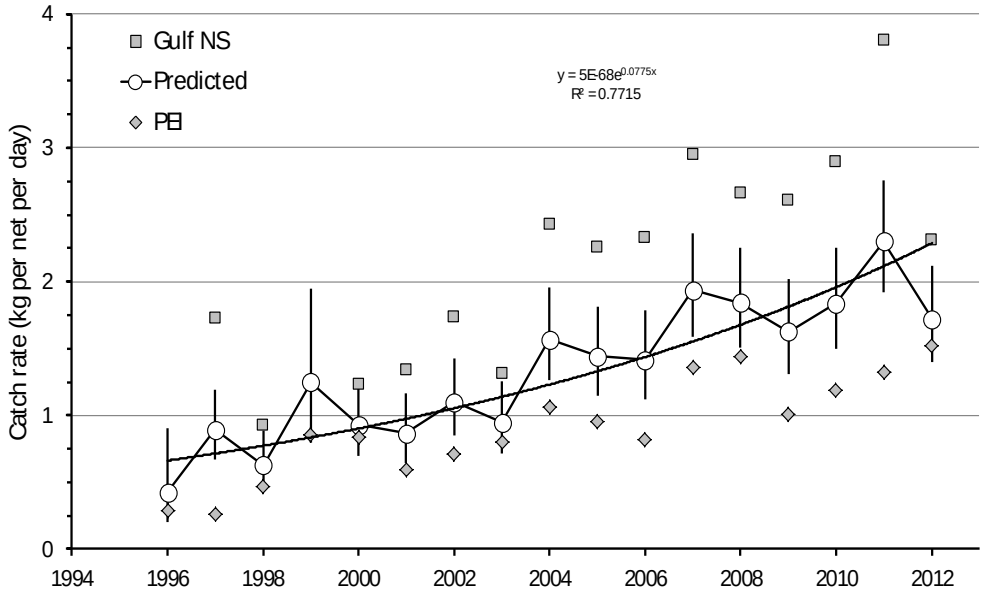

Figure 16. Increase of Eels in the Southern Gulf of St. Lawrence.

[Figure 16] is the best case of what has happened in Canada. This is the southern Gulf of the St. Lawrence, where I happen to live and work. Since the mid-1990s, three different indices in that area have increased very steadily and approximately tripled in their value. Other indices in Canada vary between these two extremes, but overall when all of the numbers are put together in an analytical framework, the overall tendency is toward decline.

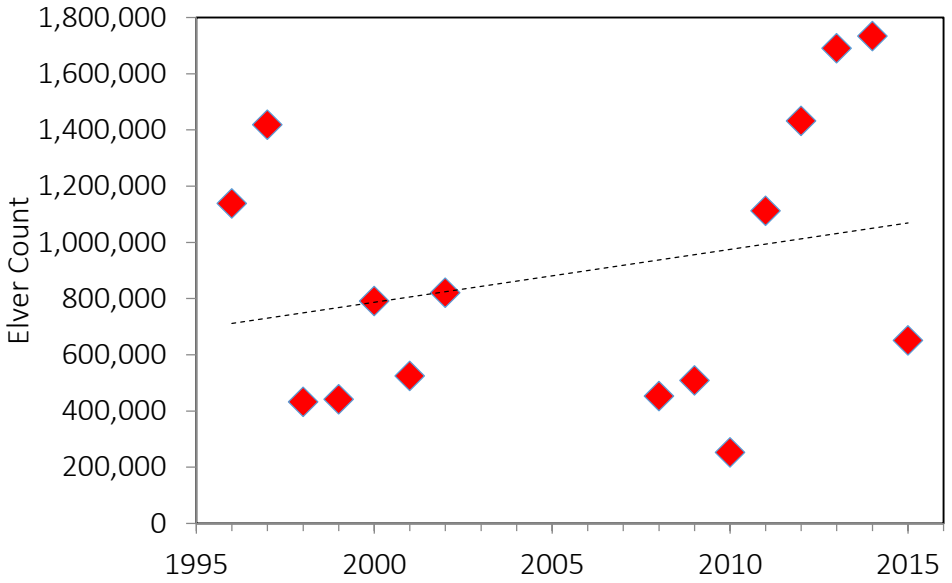

Figure 17. Index of Elvers Ascending the East River in Chester, Nova Scotia.

[Figure 17] is an index of elvers ascending the East River in Chester, Nova Scotia, not too far from Halifax. Here, elvers have been counted in a very small river coming into the fresh water over most years since the mid-1990s. This series shows a lot of variability but it nevertheless was giving some degree of optimism for the state of the American eel in Canada at least until 2014, [because] the trend was statistically significant in upward direction. However, in the most recent data we have from 2015, the [index] fell below the long-term mean.

Threats to the American eel in Canada are probably quite similar to threats across the species range, and there will be presentations later that will deal with these in more detail. Extreme loss of habitat caused by dams, especially large dams that often do not have a fish passage. Those eels that can get above those dams may be cut into pieces by turbines as they come down through the power chutes of the dam. Habitat alteration within rivers and streams – we are all the time, digging and moving and blocking. Contaminants of many kinds. Parasites, in particular one invasive species called *Anguillicola crassus* that has been in North America for several decades now, primarily in the U.S. East Coast and eastern Canada, and it has quite significant effects on the biology of the American eel. It is a species the American eel does not have effective means of resisting because it is not genetically adapted to it. In Canada it is primarily in the waters draining into the Atlantic Ocean, a few in the Gulf of St. Lawrence, but the tendency of these invasive species is that once you've got them, they keep on creeping, they keep on moving, so the pessimistic but perhaps realistic expectation would be that *A. crassus* would extend its way across the Gulf of St. Lawrence and probably into the major eel rearing, growth area in the St. Lawrence River and Lake Ontario. Ocean changes were touched on by Jim [McCleave]'s talk. My view of this whole ocean change business is that we are really at the stage where we are defining questions, not really at the stage yet of having answers to those questions. And finally, fisheries. Fisheries has a unique and special place, I think, in this whole list of threats. Not because [they are] necessarily more harmful to the species or to populations, but simply by the fact that people who talk about eels tend to work for fisheries agencies. And fisheries agencies manage and control

fisheries. So if you have active fisheries that remove or kill eels, there is an attention that is devoted to fisheries mortality that is a natural consequence of the system that we are working in.

The question of the overall impact of fisheries on American eel populations and its relative importance, with respect to the other kinds of human impactors on the species, is an open question. I did a study several years ago which looked at the distribution of eel fishing effort on the Atlantic coast of Nova Scotia, New Brunswick, PEI, Newfoundland, also eastern Quebec. We mapped the exact fishing locations on the basis of log book records, at a scale which is much finer than what is visible on [Figure 18].

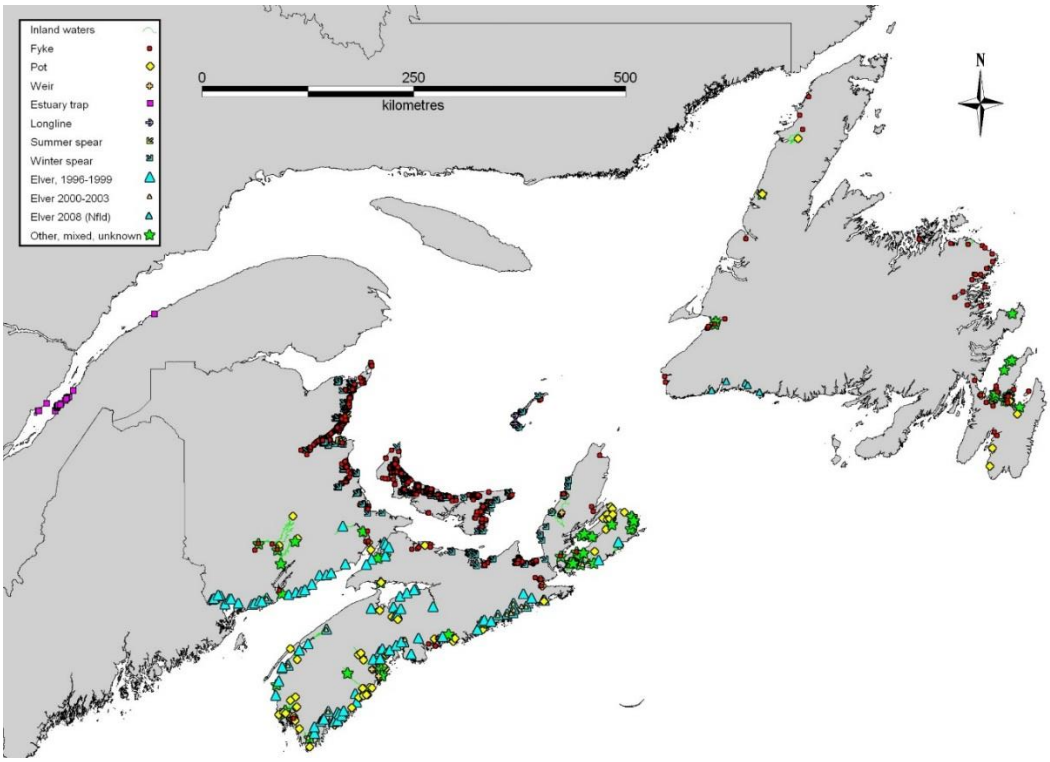

Figure 18. Eel Fishing Locations on the Atlantic Coast of Canada.

The results of that study suggested that about 96% of suitable eel habitat on the east coast of Canada is at a distance greater than 1 kilometer from any fishing gear. This would suggest that, at least in this [region], fishing may not have a large impact on eel populations.

Talking about how fisheries are managed: here is a simple, but nevertheless realistic . . . way of summarizing how commercial fish stocks are managed in western countries. You have a fish stock, and scientists who assess the stock and gather biological information and who come up with advice on sustainable harvests and so on. They [provide] that information to managers who make decisions. Stakeholders and others, who have an interest in the conservation and an interest in the economic output of the stock, also give their input and advice to managers. Managers make decisions . . . .

So, a couple of the major assumptions of this model. The fish under management constitute a stock. If you are a manager and you are only dealing with [a subset of the stock], and ignoring all of the others, your management system is not likely to be effective, because maybe someone

else is overfishing all of these other fish, and your population will shrink just because someone else is overfishing their fish; or maybe nobody else . . . is fishing there . . . , and you could have high mortality here. So for a fisheries management system to work, it has to recognize and embrace and cover the full stock. So what is a stock? A stock is a separate group of fish that can be managed as a unit. That is kind of a logic that turns on its head and is not very useful, but it is a practical management term rather than a biological term. I think for our purposes, we could define a stock as simply a species or a group of fish that operate as a breeding unit. And we know that the entire population of American eels operates as a single breeding unit, and, therefore, it is a stock.

So [under] the assumption of [the standard] fisheries management model, fish under a management [regime] constitute a stock. Is that the case [for eels]? Well, clearly not. In Canada, eels are managed provincially in Ontario and Quebec. In Canada we call this asymmetrical federalism. In the remainder of Canada, the Atlantic provinces, there are three regions, administrative regions of the Department of Fisheries and Oceans, and each of these regions manage eels directly from their own regional offices. Now there is some degree of coordination amongst these five groups, but it is certainly not an overall coherent and well-oiled governance machine. . . . In the U.S., there is certainly more coordination and a better system within U.S. waters, but really what we need is a management regime that covers the entire stock.

The second assumption is that a management system controls all of the factors that impact the stock, not just fisheries. [For eels] we know that that is not the case, fisheries is only one. So, a fully comprehensive management regime would cover all of the issues, and cover the entire stock. That is something that is a very large and distant objective. A more realistic short-term objective is a system that would cover the U.S. and Canada only, but would also serve as a forum to discuss the other conservation issues. That is something that is perhaps plausible and realistic in the immediate term.

I would like to finally make the point that while waiting for such an international governance system, there are things that we can do, and things in fact that have been done. In 2001, 2010, and 2014, ICES (International Council for the Exploration of the Seas), an international body of which the U.S. and Canada are both members, [took] initiatives to deal with the science and the assessment of the American eel. And individual scientists, including Jim and many others, have leaped over international borders to conduct international work on American eels. This is the kind of thing that can be done without memorandums of understanding, treaties and agreements.

These are examples on the science side. But, I would also suggest that on the management side, there are things that can be done even if you do not have, or do not immediately have, international agreements. People can simply pick up phones and talk to each other across boundaries, you can set up conference calls, and an exchange of perspective and view among managers in the two countries would be easy to set up and would be very useful and perhaps propel us all through the inertia and perhaps bring us closer to the formal government structures that we would like to see. Thank you for your attention.

James McCleave:

Our next speaker and final speaker in our science panel this morning is Dr. Barry Costa-Pierce from the University of New England. He is going to give us a U.S. perspective. . . .

U.S. SCIENTIFIC APPROACHES AND CHALLENGES

Barry Costa-Pierce:

Thanks, Jim. So now for something completely different. . . . My family comes from the Azores, and I just returned from Iceland where the Arctic Science Commissions that we were part of talked about this phenomenal warming that we are going through right now, this breathtaking warming, where eels are moving into a lot of the Icelandic rivers, and are moving north along the east coast of Greenland. So we are in a changing world.

As you can see, this talk is not only just the U.S. science part, it is a bit of pedagogy and science opinion about aquaculture and fisheries and maybe hopefully, giving you a little bit of a different, wider perspective of aquaculture of this particular species and its potential. Particularly in terms of the definition of aquaculture that you may have in your mind, which is growing food in water. Whereas, the aquaculture field today is just a massive toolbox, and it is a toolbox which includes conservation and restoration aquaculture, as well as capture-based aquaculture, as well as aquaculture enhanced capture fisheries. I am going to try to give you a much, much different perspective than you have heard up to this point which is mainly focused on really the traditional fields of fisheries and conservation.

We had a conference fairly similar to this, not so much on the law. It was funded by the U.S. Department of Agriculture. It did include some policy experts, but mostly it brought together the European and American scientists concerned about the potential of using a bit of the fisheries allocations to birth a sustainable aquaculture industry for jobs and economic development in this part of the world. As well as in parts of the world that particularly are not very interested in developing very expensive hatchery systems or investing literally hundreds of millions of dollars of trying to close the life cycle of the American eel.

These were some of the partners and we also brought over some of our colleagues from Europe, from Wageningen University in the Netherlands, from Denmark, *et cetera*, that have a tremendous amount of experience in the recirculating aquaculture systems for the American eel, producing a very expensive product which often times ends up on our consumer plates here in the United States.

In terms of not wanting to recreate the wheel, we were looking at what were the science aspects that needed to be included, and what was the technology transfer aspects that needed to be included particularly for the birthing of economically viable, sustainable aquaculture for this species.

It has just been a breathtaking expansion of this type of fishing, conducted with very simple dip nets now, and lights along some of our streams here in Maine. So if you look at Maine, Maine is about 5,600 kilometers of coastline. We have, if you take our islands, and our very fractal coastline and we have the largest coastline in the United Sates – California has a very lengthy coastline – but if you take our bays *et cetera* sort of *ad infinitem*. Maine also has a very distinct socioeconomic radiance. You are in where most of the people reside in the Greater Portland area, but then as you go Down East we have people dependent upon natural resource base, they are rural fishing communities, and there are some very important economic development that needs to go

on there where an ocean and cultural society. One could well imagine that if some viable economic activities that were sustainable were to rise, they would get their attention.

. . . I think our question for our symposium, and what I would like to make sure is on your mind, is . . . this the narrative that we need to sort of stay on, can we actually imagine a root for the development of what we call, we have to put two adjectives in front of aquaculture, sustainable, ecological aquaculture? Because the pathway to aquaculture that we'd be talking about is maybe not in the comfort zone of many of the people in this audience.

If you are talking about sustaining aquaculture, it is a truly interdisciplinary, or some people say "trans-disciplinary," field. As an aquaculture scientist who is very concerned we cannot actually be neglectful of anything going on in capture fisheries because capture fisheries products, the capture fisheries is not dead and dying everywhere, they present real volume and price competition for any aquaculture that you decide to get involved in. So you have to pay attention to both fields. So in our institute, we train [our students] in both. You have to be involved in conservation capture fisheries and aquaculture these days.

Here is some of what we heard about the world of eel aquaculture, which is obviously a huge business in Asia and is very technologically-advanced in Europe. . . . There is some areas that have probably higher research value for us than other areas. And research value again means that what do we actually have to invest in, and have an international collaboration in versus what do we have to have in technology transfer and bringing over bright people who already know what to do. I am not going to present a lot of the science, it is all on the website . . . it is all for the picking, it is information for the world.

We birthed something called the Northeast Aquaculture Team (the NEAT team) because we felt that we needed to continue to put proposals together that were very targeted, and this is just one that really kind of struck us. Basically what it said was that eels seem to grow in aquaculture systems faster in brackish water than they do in fresh water. Now, that may seem like so simplistic to you, but it is an incredibly important area, not only for growth and economic viability but also for what kinds of systems do we need to put out there in various locations because aquaculture is incredibly site specific in many cases.

This is the other, being a Portuguese-American extraction, again my family is from the Azores, you know I was really surprised by this. [Figure 19] was the eel value chain.

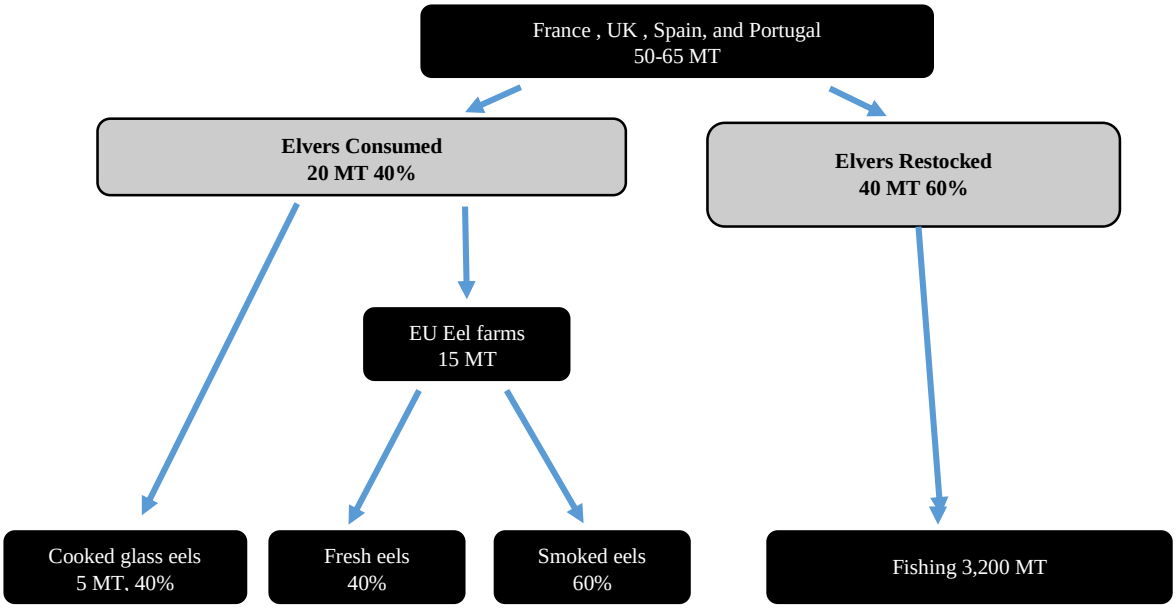

Figure 19. European Eel Value Chain.[13]

You cannot just be involved in fisheries in aquaculture. You have to understand the seafood value chains and where the markets are because the technologies that we will develop, hopefully, with fishing communities, in the future, will have to be market-driven technologies. We cannot just be scientists, determining the best ideas from technological perspectives, and then running around and trying to find markets. We did that as aquaculture scientists many years ago, and now we realize we have to work from the market backwards towards technologies. But when you look at this, we are still eating elvers. You know there is still countries in the world, Spain, Portugal, *et cetera* in Europe that are eating elvers. . . . There is a fairly major restocking program, which we have heard some concerns about today.

I am going to spend the rest of my talk [discussing culture fisheries aquaculture and capture-based aquaculture. There is most of what we have talked about today is . . . wild harvest fisheries. Again, I consider myself a fisheries scientist who works across these fields. Those of you would think I am probably going to talk a lot about this is aquaculture in the conventional sense, which is basically closing the life cycle of the animal in captivity. But these 2 fields are growing tremendously and are very unrecognized. Maybe this one you maybe know a little bit more about, which is aquaculture-enhanced fisheries. There are approximately 8 billion juvenile salmon that have been put into the North Pacific ecosystem every year from Canada, the United States, Japan, the Kamchatka Peninsula, and Russia with new hatcheries in North Korea, South Korea, and further south. There are a lot of people that think that without the aquaculture enhanced fishery, these aquaculture hatcheries throwing those juvenile salmon into the North Pacific ecosystem, that

[13] EP EDING (2014) (based on Eel Market Chain Study, FRANCEAGRIMER (2014)).

without aquaculture, those salmon fisheries in Alaska, *et cetera*, would collapse. So please realize that this is a field that is incredibly controversial in many different areas, but it is growing throughout the world. Wherever you are in Asia and you are having fishery problems, aquaculture is enhancing those fisheries.

FAO just put this book together[14] 5 years ago, and I did a major project in Mexico on captured-based aquaculture. Eels are capture-based aquaculture in many parts throughout the world, and I will get into that in a second. But the most well-known is sort of tuna stock enhancement. Taking tuna juveniles from the ocean and growing them out in large net pens. Those of you who know about this controversy in the Mediterranean, it is a huge issue. However you cannot take the Mediterranean issue of the tuna in capture-based aquaculture and transmit it to everywhere in the world because it is a sustainable capture-based aquaculture in Mexico versus the Mediterranean. I highly recommend that you get into this [book], particularly if you are interested in the kind of model that I am promoting and what came out of our symposium. It is a recent book – 2008 – and it reviews this whole field throughout the world, and it really kind of upsets a little bit the conventional wisdom about aquaculture's role in conservation enhancement as well as the development of sustainable aquaculture.

First of all, if you look at eel aquaculture, and you look at the total investment in hatchery or closing the life cycle, or you look at aquaculture engineering for recirculating systems, or systems in Asia, the ponds, you will see the vast majority of money that has been spent is on closing the life cycle. Literally hundreds of millions of dollars are being spent on closing the life cycle for American and other eels throughout the world. Whereas all of the world's eel aquaculture today is dependent upon wild caught elvers. Now, is this unusual? About 90% of all of world aquaculture today is carps in China. Up until very, very recently, that entire carp aquaculture industry depended upon captures of wild, juvenile carps from the Yangtze, Pearl and other rivers in China and then put into aquaculture systems. . . . People are beginning to understand that maybe the birthing of the hatcheries might have allowed the proliferation of dams to come in.

I am going to go through this . . . very quickly – this is true aquaculture is where you are basically closing the life cycle. You know you are taking the adults and you are doing selective conventional animal breeding selection from the adults in captivity. Now every once in a while these adults need to be replenished from the wild, so we cannot, this is not completely divorced from the wild. But over time you replenish just your brood stock from the wild. That is true aquaculture. Let's unpack this. This is what I just talked about which is closed aquaculture production network. But if you are bringing brood stock in from the wild, and you are still dependent upon the wild, that is coming into your hatchery, and then you often times as I just mentioned see adults being thrown out into the wild to enhance different stocks. This is what a lot of us have been saying now, for sustainable seafood supplies for the population on this planet, there is going to be anywhere between, the U.N. is saying between 9 and 12 billion people, we are going to need to work out this system in order to derive sustainable seafoods for the planet.

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[14] Alessandro Lovatelli & P. F. Holthus, *Capture-based aquaculture: global overview*, FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS, FAO Fisheries Technical Paper Number 508 (2008).

The question I am going to put out to you today is: is a hatchery really needed? Is our investments in trying to close the lifestyles of *Anguillas* really needed? They have extremely high capital and operating costs. We can give you FAO, Food & Agriculture Organization of the United Nations, can say in many countries of the world, some of these hatcheries are white elephants. They are very hard to maintain by governments and local institutions. With what we have talked about today, with the issues of genetics, panmixia, the question I would say to you today is that I feel that by allocating a small, not increasing the allocations out there for fisheries of elvers anywhere in the world, a very small allocation of great genetic diversity and integrity like we have heard today, diverted into sustainable aquaculture systems might be a way to not only develop jobs and economic development, might be also a way to relieve pressure on the wild. There are many, many examples today, of aquaculture systems – again, I am not talking about salmon – of aquaculture systems of many different species relieving pressure on the wild.

We put out a proposal last year, the aquaculture toolbox, these aquaculture scientists really know how to transport, how to sustain, how to pack, how to actually use the entire hatchery juvenile grow out system technologies, in order, we think, in order to lead to greater fishery sustainability. One would have to question about the elver fishing that is going on now, if we studied it along in a cooperative research fashion with the people who actually do elver fishing, can aquaculture scientists work together with those communities to actually improve the survival rates, to improve to go along the entire transportation chain all the way into Asia, to actually look at the data, and then use the aquaculture toolbox, the science that we have developed over many, many years, to allow animals to survive and be healthier, over this?

This is a recent quote from the State of the World Fisheries and Aquaculture, FAO report.[15] It is basically a clarion call to all of us, and in particular to the next generation, of leaders in this field, the young people in this audience. A clarion call that the world cannot just have capture-fisheries and aquaculture and conservation scientists. That we have to work together, particularly with species like this. I am of the firm belief that by using the aquaculture toolbox and birthing new types of sustainable aquaculture systems, that we can actually improve the fisheries, make it more sustainable, and better conserve eels worldwide. Thank you.

MODERATED DISCUSSION AND QUESTION & ANSWER PERIOD

James McCleave:

We have some time now for discussion. . . . Anybody want to shoot at us? Add to? Subtract from? Argue with?

[15] "Fisheries and aquaculture interact with increasing intensity as fishers shift from fishing to aquaculture and by competing in the same markets with similar products. The need to integrate planning and management of the two sectors seems vital to their future development and sustainability." THE STATE OF WORLD FISHERIES AND AQUACULTURE, FAO, Rome (2012).

David Freestone:[16]

I would like to start off. Panmixia is really intricate, fantastic. Three fantastic presentations, thank you. I think this has given us a great grounding for where we go – sort of policy discussions. From what I understood, from the discussion of panmixia, so it does mean that it casts some doubt on what Barry [Costa-Pierce] was just saying about the aquaculture enhancing species being a simple answer to this question, in the sense that if you capture them in one place they are going to have different characteristics. That is what I have understood. Some ideas on how, if we bring what we are doing in the European context states together in a means to develop collaboration that was said at the outset. So, what kind of mechanisms would you identify as being really important for international collaboration on the American eel? Very useful help.

Barry Costa-Pierce:

. . . Jim [McCleave], I want you to please weigh in on this opinion the way I am interpreting the genetics information that you gave us. So there are many examples of, in aquaculture, the most sophisticated aquacultures we do vary in detail, familial, selection creating synthetic strains – we did this in tilapia, we did this in shrimp, we did this in salmon. Basically, that is not what we are talking about. That is one type of aquaculture there where conventional animal breeding has brought a synthetic strain of great characteristics after lots of bioprospecting and lots of familial selection. It says now, I have a gift fish, a genetically improved fish. That is what they do call it, gift tilapia. That is not what we are talking about here because there are all kinds of other aquacultures that do not do genetic improvement and familial selection like that. They actually continue to go back to the wild and capture wild juveniles of great genetic diversity, which I think we are talking about here, and use that genetic diversity to not sort of "pollute the gene pool." There is a very large concern that some of those highly selected individuals would be released into the wild, and somehow harm the wild populations. I guess what I am advocating here is that if you look at the capture-based aquaculture review of FAO, you will see that there are many, many aquacultures throughout the world that do not do that. They use wild elvers of great genetic diversity like in this case, and move them into aquaculture. And that is the hypothesis that I am giving here that eels are no different than some of these others.

David Cairns:

The point that I would make is that alteration of the genotype of a wild animal can be additive or subtractive. An example of additive would be if there is an escape of domesticated salmon from a net in the Bay of Fundy, those animals go out and breed with wild salmon and add to the gene pool and shift the gene pool of the wild salmon. That is not what we are talking about here. But subtractive effects can happen as well. There is certainly concern in the eel science community that the fact that we have constrained and limited fresh water eel production, quite considerably, so we think, by all of the things we have done in fresh water dams and so on, to the

[16] Executive Secretary, Sargasso Sea Commission.

point that there are fewer fresh water eels being produced in fresh water that go up to the Sargasso Sea to spawn, so the spawning pool now, at least as an initial conjecture, contains a lower proportion of adaptive genetic traits that help eels draw in fresh water now than they might have in decades, or years, centuries past. So any kind of capture fisheries, which is also removing animals from the wild, whether it is conventional, commercial fisheries also aquaculture fisheries, so if we are thinking about a new model of use of eels through the kinds of things that we just heard, one of the considerations would be how that subtractive impact would impact the stock as a whole.

William Bradnee Chambers:[17]

Thank you for some excellent presentations. James [McCleave], I had a question for you. As a global agreement, we work on all types of laboratory species, but the range is really important for us and it offers the strategies we put in place for a particular species. I was really interested in learning about your paper on the Caribbean population. Any idea of the size of the population there compared to – is it 20% of the entire population – any indication at all of the size?

James McCleave:

We could not find any real estimates of population sizes there. Most of the records that we found are somebody did a little study or somebody collected and there is a bunch of specimens in the Smithsonian or whatever. To the best of our knowledge, there had not been any real scientific studies of abundance and none of recruitment of glass eels. So, I think the answer is we just do not know. There is probably good indication of trends in Puerto Rico for example where scientists have [surveyed] essentially all the major drainage system and where there is existence, that would give us an idea of reductions, relative reductions in the population size but we do not know what the starting point was. One of the things I think José and I sort of joked about was who can we get to send us to the Caribbean to march from island to island? But I think that is an important question, whether those eels in that wider region, taken collectively, account for a good portion of the stock? But I really do not know.

Mike Waine:[18]

I think my question is probably most relevant for David [Cairns]. I am curious – you talked a little bit about the management scheme in Canada, but could you talk a little bit about the science that drives some of that management? And if there is any sort of population estimates, or specific research that drives the management that goes on for the species?

David Cairns:

[17] Executive Secretary, Convention on Migratory Species.
[18] Senior Fishery Management Plan Coordinator, Atlantic States Marine Fisheries Commission.

Well the background to that is that in most of Canada and the U.S., there are 2 parallel streams in assessment, management and so on. The slide that I showed fisheries management and science models applies to the conventional way that fisheries have been managed for 30 or 40 years. But in the past several decades, another parallel stream has come along that has to do with endangered species management and conservation. And in both countries you have the endangered species box and then you have the conventional management box. In Canada, the endangered species, species at risk box, is based on COSEWIC assessments and government listing and so on. There is a formal prescribed process that is prescribed in legislation that we have gone through. On the management side, there should be, one might say or one might expect, that there would be a parallel management process to assess American eels within Canadian waters, and to establish estimates of sustainable eel and so on and so forth, and that has never happened in Canada. So, on a national basis, what we have is a science that deals with the species at risk side of things. Obviously we are talking about the same animals, you are trying to conserve them on both sides, but the orientation is somewhat different on this species at risk side, you are trying to prevent animals from sliding into some kind of endangerment. Whereas on the fisheries management side the analysis is oriented towards determining harbors that are sustainable. So, the U.S., both sides have been addressed by the U.S. Fish & Wildlife Service, the ESA evaluations and the Marine Fisheries Commission benchmark assessment, so you are working on both sides in the U.S. In Canada, we are really only working on one side.

Jeff Thaler[19]:

It is very difficult for policymakers, courts, regulators to make decisions when there is a lot of scientific uncertainty. And it seems with the American eel, it is a classic situation with a lot of uncertainty as you all were saying. If you had to say and pin down in a court or elsewhere, what is the number one thing that would be most important to try to get more definitive data or information or results for the American eel that might then lead to more comfort levels for regulators to take action, what would it be? You have all posed a number of questions and uncertainties, plausibilities or otherwise, but what needs to be addressed? What should be the highest priority of scientists in answering questions on the American eel?

James McCleave:

I am not sure how to answer the question. I do want to mention . . . that at the University of Maine we have an annual Senator George Mitchell lecture. It was presented by Roger Pilky from the University of Colorado, a policy person, a couple of weeks ago. One of the points he made was that scientists should not tell policymakers what they should do. Instead, scientists should be able to offer options to the managers, regulators, and the legal community. If you did this, these are the pro's and con's. If you did that, these are the pro's and con's. And, if you did [something else], these are the pro's and con's. If I were to say as a scientist, where do I think

[19] Assistant University Council & Visiting Professor of Energy Law, Policy & Ethics, University of Maine.

efforts need to go, they are twofold. One is a situation we cannot do very much about. A lot of the uncertainty is what is going on in the ocean. Eels are not going to be important enough to sway the climate change debate, I think.

The other thing I think I alluded to is that we are just on the verge of understanding what that genetic diversity means after natural selection has acted on it to give us a geographic distribution in which the genetic components are not equal. What are the implications then for the rest of the life history for individual eels that are coming in from certain waterways? That is something that we can tackle, and it might lead us to assistance for aquaculture, it might lead us to understand what we can do better by manipulation of stocks to enhance depleted fisheries. My opinion only.

Alan Walker:[20]

Two points very quickly. You did mention last night that in terms of the expletive punishment, and the comparability across the range, would be incredibly useful. David [Cairns] presented a number of figures today for data from different places, and they are all a little bit different. It allows lawyers and everybody else to say well, that's different from that so therefore the science is unsure. It is about the aquaculture and you talked about the genetics. My equal concern is about the phenotype, which is the select beast rather than the genetics behind it. We understand a little bit that when eels grow faster or slower they change, they become predominantly males or females depending on their growth. And if you put them into aquaculture, the challenge is how can you produce an eel that would have been the same as it had been if it had been left in the wild? We have had this situation in Europe where people wanted to focus [their] effort into the Mediterranean because that produces silver eels very quickly, so you get a fast response. But the problem might be that it produces male eels and that might not be good for the survival of the species. So just a warning that in aquaculture it is not just the genetics, it is the phenotype as well.

Barry Costa-Pierce:

Yes, I think it may be bordering also on the legal discussion. There are some international conventions that we can all to agree to and one of them maybe not be familiar to many of you. We have a code of conduct for responsible fisheries but now we have the FAO's ecosystem approach to aquaculture. The ecosystem approach to aquaculture builds upon the code of conduct for responsible fisheries. In other words, it says that you do not develop aquaculture at the expense of sustainable fisheries. And you look carefully at the scientific connections between them. For example, in this particular case one would never advocate increasing the allocations for eel elver fishing that the hypothesis is that more sustainable elver fishing at the current levels, or even lower, could occur with a birth of a small portion of that allocation to aquaculture. That would be one sort of route that would meet both of those international conventions and potentially lead to potentially jobs and economic development in some of the socioeconomic regions that need it for harvesting elvers, like in our state. I think that there are many routes to harvest a genetically diverse population

[20] ICES/WGEEL Chair, CEFAS.

and bring them into recirculating systems with no escapement controls that would not harm the wild genetic diversity. I think that we are at that point now. And also to put it into the legal framework where escapes do occur, there is a fairly heavy hammer for that.