12 April 2016

To Whom It May Concern:


From: Dr. Robert S. Steneck, Professor of Marine Biology, University of Maine’s School of Marine Sciences.

I have studied the biology and ecology of lobsters for over 30 years. I was asked to evaluate the proposal to list the American lobster as an “invasive alien species” in European waters. I have no vested interest in this subject. Below is my evaluation based on the best available science.

Summary:

The above listed article requests that the American lobster, Homarus americanus, be listed as an invasive alien species in European waters. All evidence that we have today indicates that the American lobster is not currently and may not be capable of ever meeting the definition of “invasive”. I see no support for the arguments that it poses a clear and present danger to European waters.

Is the American lobster “Invasive” in European waters?

The most widely used definition of invasive is given in The National Invasive Species Council (https://www.invasivespeciesinfo.gov/docs/council/isacdef.pdf). It defines an invasive species as “an alien species whose introduction does or is likely to cause economic or environmental harm or harm to human health.”

Since several studies looked for, but found no evidence of, successful reproduction outside of the western North Atlantic (e.g. van der Meeren et al 2010) the first necessary requirement for establishing a non-native population has not been met. This was acknowledged on page 4 in the proposed request from Sweden (listed above) with the statement “It is uncertain if H. americanus has so far established any populations in the European Atlantic region.”

In the “Invasive Alien Species Fact Sheet” for Homarus americanus (van der Meeren et al 2010) every EU country in the North Atlantic is listed and the five in which H. americanus has been found, is listed as “Not established”. The authors define not established to mean “The species has not formed self-reproducing populations (but is found as a casual or incidental species”). They go on to point out that “Intentional implants to areas outside the range of the Homarus species, like the American West coast, Japan and Oceania, have not been successful.”
It seems logical that a population not known to reproduce cannot directly cause economic or environmental harm or harm to human health. In fact, there has never been a risk to human health caused by American lobsters. The van der Meer et al 2010 report lists “Human health effects” as “None”. Even lethal diseases in North America pose no human health risks (more on that later). Therefore the American lobster does not meet any aspect of the definition of an invasive species in Europe today. The scientifically correct language would be that this is a “non-native” or “alien” species.

Is the American lobster capable of establishing a viable population in EU waters?

"Article 4(3)b – They are found, based on available scientific evidence, to be capable of establishing a viable population and spreading in the environment under current conditions and in foreseeable climate change conditions in one biogeographical region shared by more than two Member States or one marine subregion excluding their outermost regions."

The request asserts that the western North Atlantic and “European Atlantic region share very similar climates...” That is incorrect. Although there are overlaps of temperatures between the two regions, the annual temperature range is much greater in the native range of *H. americanus*. There is considerable evidence that temperature drives biogeography. In general and specifically for *Homarus* the average summer and winter temperatures define the distribution of the species (Fig. 1).

Average Min Temperatures (Dec-Feb)

![Thermogeographic differences between the regions dominated by *H. americanus* vs. those dominated by *H. gammarus*. Each point (x) reflects 60 miles of coastline (data from Adey and Steneck 2001). Summer temperatures are represented by “Average Max Temperature” and winter temperatures are represented by “Average Min Temperatures”. Specifically note how much colder winters are in the regions where *H. americanus* lives such as Eastern Canada.](image-url)
Differences in winter temperatures are likely most important (e.g. Fig. 1). In an important study by Aiken and Waddy 1986 entitled "environmental influences on recruitment of the American lobster, *Homarus americanus*: a perspective", temperature was identified as the single biggest factor affecting "oocyte maturation and the incidence and synchronization of spawning". They show that "winter temperatures above 8 – 10°C the incidence of spawning will decrease" and eggs will fail to develop. They go on to state that the winter seawater temperature affects the synchrony of molting in American lobsters. "When winter temperature is no lower than 12°C, molting can occur in all months of the year." Since lobster copulation requires molting this could affect fertilization success and/or timing of the subsequent hatch. They go on to state; "When winter temperature is 0 – 3°C, molting is concentrated in the summer and autumn months" when egg development and hatching will be optimized for larval and settlement success.

Therefore the best available science does not support the assertion that *H. americanus* is "capable of establishing a viable population and spreading in the environment under current conditions and in foreseeable climate change conditions in one biogeographical region". Not only are the two species found in different biogeographic provinces but also current EU winter temperatures are too warm for successful reproduction (e.g. Aiken and Waddy 1986). With climate change winter temperatures are expected to increase not decrease.

"4(3) c – They are, based on available scientific evidence, likely to have a significant adverse impact on biodiversity or related ecosystem services and may also have an adverse impact on human health or the economy."

If populations of *H. americanus* are not known to be able to reproduce in EU waters, then there is no scientific evidence that they will have a direct adverse impact on biodiversity or related ecosystem services. However, there is concern about indirect impacts resulting from diseases or parasites found on American lobsters.

While all evidence suggests the inoculum of American lobsters to European waters is low it is not zero. The American lobsters found in EU waters have all been held or released illegally. This is supported by evidence of their abundance being greatest around fish auction halls and close to airports (van den Meeren et al 2010).

Could diseases from American lobsters spread to European lobsters? That is possible but in all likelihood, the diseases are already in EU waters just as they had been in US waters for decades prior to the disease outbreak (Castro et al 2006). To date all of the demographically important diseases affecting *Homarus* require high population densities and physiologically stressed lobsters for an epizootic outbreak (Castro et al 2006, Dove et al 2005, Steneck and Wahle 2012). While it is a fact that sea temperatures in Europe will increase, the chance of having high population densities of lobsters at summer temperatures exceeding a stress thermal threshold of 20°C is very low.

The other biodiversity concern relates to the American lobster being a potential vector for the introduction of "other invasive alien species such as barnacles, polychaetes,"
nematodes..." There are no lobster-specific barnacles so the species that happen to attach to lobsters could inoculate EU waters. However, those same species and groups are all found on ships arriving from the US and elsewhere. If we assume the EU is comfortable with the risk of those non-native species being found on the hulls of cargo ships, then the additional risk posed by the few lobsters found in Europe to date must be within acceptable levels. Certainly no double standard should be applied to lobsters that do not exist for ships.

"4(3) d – It is demonstrated by a risk assessment carried out pursuant to Article 5(1) that concerted action at Union level is required to prevent their introduction, establishment or spread."

Since the American lobster is not known to reproduce in Europe and if it ever does, the best available science suggests its populations will remain low, so the associated “risk” must be low. To date the only real risks result from illegal activities identified on page 5. There is logic in enforcing the laws for handling and marketing of live lobsters. The same would hold true for other species of clam and oysters that are marketed live in the EU.

Sweden is the 9th largest importer of seafood in the world (Inside Sweden 2015). All fresh fish from other areas of the world will contain non-native parasites. Any of those skins tossed into Swedish waters have the same risk of disease as exists on the surface of a live lobster exoskeleton. So if a completely risk averse strategy is adopted (and again, no double standard is applied), then many other seafood species would pose the same risk and would be subject to an import ban.

Literature Cited:


Preliminary review and analysis of Sweden's Risk Assessment on the potential impacts of the American lobster trade in Swedish waters.

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Section 1. introduction
The Swedish Agency for Marine and Water Management produced a Pest Risk Assessment ("RA") on the introduction of American lobsters (*Homarus americanus*) into Swedish and European waters, which was adopted in December of 2015. The RA document is used as the basis for a request from Sweden to the European Union to include *H. americanus* on the list of invasive alien species, which could result in a ban on live imports of *H. americanus* to EU countries. The RA summarized information from the peer-reviewed scientific literature, as well as information from regional experts, to describe the risk of *H. americanus* entry, establishment, spread, and potential impacts (ecological, economic, and social).

The potential ban of the live *H. americanus* trade between the U.S. and European Union (EU) countries raised a number of concerns within the U.S. lobster industry and its affiliated stakeholders regarding loss of economic opportunities under restrictive precautionary principles. As a result, several industry organizations and the National Fisheries Institute convened a group of U.S. lobster biologists from various government fisheries agencies (state and federal) with the intent to review the science presented in the Swedish RA and generate a document summarizing this review, placing topics in the review in the context of relevant scientific literature and providing resulting conclusions. This document is a collaborative effort between biologists from the National Marine Fisheries Service and the states of Maine, Massachusetts, and Rhode Island, with contributions from biologists from New Hampshire and from the Virginia Institute of Marine Science, and represents an objective review of the available scientific information relevant to the RA. This document focuses solely on the biological aspects of the issue, not the socio-economic aspects.

Section 2. Characteristics of invasive species and successful invasions, and potential for establishment of *H. americanus* populations in EU coastal waters.
Concerns about biological invasions and their impact on ecosystems, native species, and the economy have led to recent and ongoing widespread government actions to try to prevent and manage these introductions that potentially could lead to future invasions and continued spread of non-native species. The EU Regulation No 1143/2014 addresses these issues for the European Union and provides a framework for the European Commission to review risk assessments of potential species to be listed as an Invasive Alien Species (IAS). This process has brought recent documentation of American lobster (*Homarus americanus*) individuals found in the coastal waters of Europe (Great Britain, Norway, and Sweden) to the attention of the Commission as a potential invasive species. It is undisputed that *H. americanus* have been found surviving in the wild in several EU locations, and they are not native to European waters, but the assessment of the likelihood that a reproductive population will be established (i.e. invasion) has a large amount of uncertainty and additional factors that should be considered.

The EU regulation 1143/2014 recognizes that "the appearance of alien species...in new locations is not always cause for concern [...and that] only live specimens, and parts that can reproduce, represent a threat to biodiversity and related ecosystem services, human health or the economy, and therefore, only those should be subject to the restrictions under this regulation." Thus far, evidence of
H. americanus in European waters demonstrates that introductions have occurred, though the magnitude is unknown. The current evidence does not indicate that H. americanus have established a reproductive population, because all reported H. americanus individuals have been legal-sized adults (thus likely to have been originally harvested in North America; see information included in the Swedish RA). After initial introductions, invasion-related time lags may occur before any evidence of an established reproductive population can be detected (Crooks 2005), however it could be argued that imports of live H. americanus have likely taken place since the implementation of transatlantic jet transportation in the 1960s (Alderman 1996). Potential escapements and introductions likely occurred throughout that period yet a reproductive population has not been detected, even with the level of fishing for the native species, Homarus gammarus (see below).

The Swedish Risk Assessment lists attributes of H. americanus that make successful invasion more probable, including larger body size, long life span, higher fecundity, high adaptability, and habitat generalism. Researchers of invasive species have attempted to find consistent biological and environmental characteristics that predict invasions and compiled a long list of attributes including (but not limited to):

• high intrinsic growth rates
• short generation times
• early sexual maturity
• rapid growth
• high fecundity
• high parental care
• long life span
• gregariousness
• rapid dispersal
• broad diets
• broad physiological tolerance
• large native range size
• less tendency to migrate
• lack of natural enemies, competitors, parasites, or diseases in the new ecosystem
• presence of comparable climates and habitats
• prior invasion success

The above attributes have been compiled from several scientific sources describing various different organisms with different capabilities (Crawley 1986, Ricciardi and Rasmussen 1998, Kolar and Large 2001, Wolf 2002, Hayes and Sliwa 2003, Marchetti et al. 2004, Lockwood et al. 2005, Devin and Beise 2007). Such research has had varying success, potentially because many of these characteristics are interrelated and may be correlated with other, unexplored variables (Marchetti et al. 2004, Lockwood et al. 2005). For example, organisms usually exhibit high intrinsic growth rates because they have high fecundity, early sexual maturity, and short generation times; qualities that allow an invader to establish a population and spread quickly, given a brief window of appropriate environmental conditions. However, such animals usually do not have long life spans, a characteristic assumed to be useful for reproducing across multiple years. Similarly, organisms with broad diets and physiological tolerance are
more likely to have large native ranges, and thus would be more likely to encounter appropriate climates and physical habitats.

For the case of *H. americanus* and Northeast Atlantic waters, this is a mixed list. *H. americanus* does have a long potential life span (decades), higher fecundity (relative to the native species), a generalist diet (similar to *H. gammarus*), and habitat preferences that are compatible with the Northeast Atlantic shelf (see Section 3). It also exhibits moderate parental care for a marine invertebrate (brooding eggs until hatch) and moderate potential for dispersal, both in the larval and adult stages. However, it does not exhibit characteristics associated with high growth rates, short generation times or early maturity, as age at 50% sexual maturity is estimated at eight to nine years in the southern Gulf of Maine (ASMFC 2015, based on data from Little and Watson 2003, Watson et al. in prep). Given that *H. americanus* would be introduced into an environment currently populated by a sibling species, the new habitat would not be free of predators (including humans), competitors, parasites, or diseases, so the population would not be free to grow unchecked. In fact, reports indicate that the potential predator suite is actually more diverse in the NE Atlantic than in the NW Atlantic (Linnane et al. 2001, Mercer et al. 2001, Ball et al. 2001). Further, *H. americanus* are not gregarious, and their ability to locate conspecifics over large distances for mating purposes is unknown, so small populations may exhibit low fertilization and reproduction rates (i.e. mate-finding Allee effects, see Gascoigne et al. 2009).

Researchers have repeatedly found that a history of past invasions by a species can be an important predictor for assessing future potential invasions (Riccardi and Rasmussen 1996, Marchetti et al. 2004, but see Hayes and Sliwa 2003). Ecologists separate the process of species invasion into distinct stages, including transportation, release, establishment, spread, and invasion (Vermeij 1996, Kolar and Lodge 2001) and have further noted that characteristics conducive to completing one stage may not be advantageous for subsequent stages (Kolar and Lodge 2001). Establishment is defined as the persistence of a population that can sustain itself through local reproduction and recruitment (Vermeij 1996). It is notable that consistent and repeated introduction, natural or otherwise, of a species into another habitat can be mistakenly interpreted as population establishment (Vermeij 1986, Simberloff 2009). After establishment, the population must grow and spread geographically and ecologically impact other species before being considered invasive (Colatti et al. 2006).

In the case of *H. americanus*, there have been several opportunities for populations to establish outside its native range, including several intentional releases referenced by the Swedish RA in Japan, France, and the Pacific coast of North America (reviewed in Nicosia and Lavalli 1999), but there is currently no evidence for successful population establishment resulting from these introductions. The introductions in Japan likely failed primarily due to a thermal mismatch of the ecological needs of *H. americanus* (Kittaka et al. 1983), and in France introductions were of hybrids, also introduced into warmer waters (Latrouite and Lorec 1991, and see Section 3 regarding temperature). Invasion success can be particularly idiosyncratic, with species often failing multiple times despite species having "invasive characteristics" before becoming successfully established (Carleton 1996, Simberloff 2009).

Recent research has emphasized the importance of propagule pressure, or the number of individuals, in invasion success (review by Simberloff 2009). Both in meta-analyses and manipulation experiments, metrics of propagule pressure have been found to be strong predictors of invasion success, typically stronger than the biological or ecological characteristics discussed above and often correlated with these biological and ecological characteristics (Marchetti et al. 2004, Lockwood et al. 2005,
When propagule pressure is accounted for in a study, biological and ecological characteristics are often no longer effective predictors of invasiveness, suggesting that past correlations between biological and ecological characteristics and invasiveness may be spurious. After propagule pressure has been accounted for, the most consistent and often only remaining biological or ecological predictor of invasion success is habitat and climate compatibility (Cassie et al. 2004). Given that habitats in portions of the EU appear to be appropriate for *H. americanus* (see Section 3), understanding the scale of recent releases, both in terms of number of animals and spatial extent of releases, is critical to determining the probability of establishing a population.

Propagule pressure is the combination of propagule size (number of individuals in a single introduction event) and propagule number (number of introduction events). The failure of small populations can often be attributed to low propagule size or low propagule number due to demographic or environmental stochasticity, respectively (Simberloff 2009). Demographic stochasticity involves random variations in population sizes that are more pronounced in small populations due to the inherent variability in reproductive or mortality rates or sex ratios at small numbers (i.e. for a population size of three individuals, there is a 1/3 chance that all individuals will be of the same sex). Large propagule sizes mitigate the effects of demographic stochasticity by decreasing the probability of such random occurrences. Environmental stochasticity, on the other hand, involves the chance that propagules are released in an incompatible habitat, under inappropriate conditions, or that a localized population is extinguished by an environmental event (hurricanes, floods, etc.). Thus, multiple introduction events (propagule number) makes it more probable that some introduced individuals will encounter appropriate ecological conditions and avoid environmental disasters.

The numbers and spatial distribution of *H. americanus* recently recorded in European waters provide some indication of the magnitude of introductions, and describe at least the lower bounds on the number and size of introductions to-date. Table 3 in the Swedish RA lists 23 wild captures of *H. americanus* over a period of three months in 2014, with no records in the four years prior to this period and no records for nine months after this period, though various factors may affect reporting rate. Within these three months, the captures are further grouped temporally with the largest “group” consisting of 12 individuals captured over 17 days. Information is not provided on where each of these recaptures happened (presumably the Gullmar Fjord), which of these individuals still had bands on their claws, or how they were collected, so it is unclear if this represents multiple introductions of a few individuals or fewer, larger introductions, or perhaps even a single incident resulting from mishandling by purchasing agents or markets. However, the lack of reports before or after this period suggests that a large portion of released individuals were recaptured by the fishery. Similarly, 29 *H. americanus* were captured along the Norwegian coast over a 16-year period and 26 individuals were captured in Great Britain between 2011 and 2015. Thus, with the exception of the recent reported intentional release of a large number of individuals in Great Britain, a few hundred of which have been recaptured, most introduction events appear to involve only a few individuals.

Similarly, it is possible to estimate the minimum size for introduction to result in an established population based on the literature. Although it is possible for species to successfully establish a population with only a few individuals (Crawley 1986, Long 2003, Simberloff 2009), successful invasions usually require larger numbers. Marchetti et al. (2004), when analyzing the effect of propagule size on successful invasions by fishes, used “less than 100 individuals” as the smallest propagule size category,
assumed that species introductions via ballast water involved 1,000 - 10,000 individuals, and concluded that invasion success dropped rapidly below 1,000 individuals. Bierne (1975 in Simberloff 2009) found that 78% of introduced insects successfully established populations when propagule pressure (total across multiple introductions) exceeded 31,200 individuals but dropped to 10% success for less than 5,000 individuals. Red king crab, *Paralithodes camtschaticus*, were successfully introduced into the Barents Sea after the intentional release of “1.5 million first-stage zoeae, 10,000 1-3 year old juveniles,” “…and 2,609 5-15 year old adult crabs” over the course of nine years (Orlov and Karpevich 1965, Orlov and Ivanov 1978 in Jorgensen and Nilsen 2001). While this was obviously sufficient to establish a population, it is unknown if a much lower propagule pressure would have still been successful. *Chionoecetes opilio* also successfully invaded the Barents Sea, but via unknown vectors and with unknown initial numbers. In the late 1990s there were 15 individual crabs reported over the course of four years (see Agnalt et al. 2011), whereas by 2014 *C. opilio* was considered a major component of the Barents Sea ecosystem and a commercial fishery has developed (Hjelset 2014).

Birds seem better able to establish populations with smaller propagules. Green (1997 in Simberloff 2009) reported a 6% rate of successful establishment for propagules of less than 10 birds and Newsome and Noble (1986 in Simberloff 2009) report one successful establishment out of 16 introductions for propagule sizes below 20 individuals. Birds may have a lower minimum propagule size than other taxa due to excellent long-range vision to assist with mate location, as well as a tendency to be gregarious, keeping a small number of individuals together and increasing the probability of successful mate encounters.

As far as the potential for *H. americanus* to establish and invade European waters, we note that there are several qualities that distinguish *H. americanus* from invasive species recognized by the EU commission. All of the species thus far listed as Invasive Alien Species by the EU Commission have demonstrated widespread and current establishments of reproductive populations in non-native ecosystems globally (https://circabc.europa.eu/faces/isp/extension/wai/navigation/container.jsp). Many of the terrestrial species were intentionally introduced in ornamental gardens then became noxious weeds, while aquatic species were intentionally introduced for aquaculture or via the aquarium trade. For all of these species, the intention was to hold the individuals though a normal life span and potentially propagate the species in Europe. Another EU listed category of species is crayfish (especially *Procambarus clarkii*), where some were introduced accidentally, but most were deliberate introductions according to the RA presented to the EU Commission. Some crayfish species are widely recognized as invasive species globally and, while taxonomically similar to lobster species, their life histories are quite different. Regarding parental care, female *H. americanus* carry their eggs for a long period of time (9-12 months, Butler 2006), and upon hatching larvae are released into the water column and disperse via ocean currents for several weeks. In crayfish, the incubation period is generally only about three weeks and once the eggs hatch, the female cares for those hatchlings for additional weeks (http://www.crayfishfacts.net/crayfish_life_cycle/crayfish_life_cycle.html) so the level of parental care is much higher in crayfish and potential for dispersal lower than in Homarid lobsters. *H. americanus* does not fit well into any category within the EU Commission’s potential and listed invasive species, being solely a live seafood product whose import and export is intended for human consumption and not for propagation.
Assessing the potential for establishment of *H. americanus* in European waters is unusual compared to other case studies of species invasion and further complicated by the fact that the ecosystem is already inhabited by a sibling species with which *H. americanus* may interbreed. The potential for hybridization is not well understood (see Section 4 on hybridization) but is critical for assessing how a population of *H. americanus* might establish. We can consider a continuum of hybridization potential with interbreeding being impossible due to behavioral or biological factors at one extreme, and with no such barriers to interbreeding at the other extreme. The existence of several recaptured *H. americanus* bearing hybrid eggs are evidence that the former extreme is not the case but available research on mate selection suggests that there is some deterrence for interspecific mating (van der Meeren 2008), which is evidence against the latter extreme. Thus, we consider an intermediate scenario where individuals of both species prefer to mate with conspecifics but will mate interspecifically if a mate of the same species cannot be located. Under this scenario, the potential for hybridization actually functions to deter the establishment of populations of *H. americanus*.

To understand the potential impact of hybridization on establishment success, it is useful to track the gene frequencies of the alien species in the context of the whole population of residents. Presumably, any introduction of *H. americanus* would initially constitute a very small number of individuals compared to the local, resident population of *H. gammarus* and, if not captured by the fishery, the introduced individuals would disperse and intermix with the native species. While *H. americanus* can use chemical cues to find mates over short distances (Bushman and Atema 1997, reviewed in Atema and Steinbach 2007), the ability of lobsters to locate conspecifics over longer ranges is unknown. As a result of intermixing, skewed species ratios (more *H. gammarus* than *H. americanus* individuals), and mating preferences, female *H. gammarus* will presumably be able to find a male *H. gammarus* to mate with, but male *H. americanus* may not mate at all unless they encounter a female *H. americanus*. Thus, *H. americanus* males may be functionally excluded from hybridization, in which case the frequency of *H. americanus* genes would be cut approximately in half within the first generation. If similar mate choice and selective breeding applies to hybrid lobsters (i.e. *H. gammarus* females will prefer *H. gammarus* males over hybrid males, which seems plausible), this mechanism will persist through future generations, further reducing the frequency of *H. americanus* genes in the gene pool. Further, the RA reports that some of the observed hybrids are sterile and therefore a dead end to their genes. The RA also points out that hybrids would most likely have a thinner cuticle than *H. gammarus* and, “thereby lower ... resilience to disease and physical damage.” Thus, multiple factors are in place to significantly and rapidly remove *H. americanus* genes from the general population. Fertile hybrid lobsters would have to exhibit an otherwise enormous selective advantage over *H. gammarus* to counter this and for *H. americanus* genes to proliferate.

For cases where *H. americanus* successfully mate with a conspecific, or a gravid female *H. americanus* is harvested from North America but does not spawn until reaching EU waters, the resulting larvae would disperse for several weeks, have to find appropriate settlement habitat, then forage, avoid predators and recapture by the fishery for several years until they reach sexual maturity, and then locate another *H. americanus* in their environment to successfully reproduce. The tendency for larger adults to perform seasonal migrations further complicates conspecific mating success by further diffusing individuals across the seascape.
This leads us to conclude that successfully establishing a population in another ecosystem populated by a sibling species would probably require a large propagule of individuals that are not effectively recaptured by the European lobster fishery in order for conspecific encounter rates to reduce the rates of hybridization and overcome the effect of diffusion over time. Further, for the population to establish and grow, environmental conditions would have to remain locally favorable and fishery exploitation would have to remain low enough for individuals to reach sexual maturity, given that they would be presumably recognized as alien and removed by the fishery not from legal size but from the size of first capture.

Although there is no evidence that populations of *H. americanus* have established in European waters, the RA states in several places that such populations could exist and not yet have been detected. The intensity of the existing fishery for *H. gammarus* may be used to estimate introduction rates and the probability of detecting breeding populations of *H. americanus*. Fishing mortality rates for legal-sized males in the UK vary regionally from ~0.5 – 1 (Bannister and Addison 1986, Bannister and Howard 1991, Addison and Lovewell 1991), suggesting that 40 - 60% are removed annually. By extension, each legal-sized lobster of either species within the *H. gammarus* stock area would have a 40-60% chance of capture per year, other things being equal. We have not been able to find any estimates of exploitation rates on *H. gammarus* in Norwegian or Swedish waters. Exploitations rates in Norway and Sweden may be comparable to the UK, given the low stock status and how rapidly *H. americanus*, accidentally released into European waters, were recaptured by the fishery. However, they may be lower given the smaller size of the fishery and extent of coastal habitat in these countries. Regardless, exploitation rates would have to be very low regionally for introduction rates to be much larger than currently reported or for a population of *H. americanus* to go undetected. Given basic data on sampling effort, either from scientific surveys or fishing activities, we note that it would be possible to actually calculate the probability that an undetected population exists in a defined area, using basic statistics in simple situations or simulations for more complex situations. Given the importance of this decision, it seems that this would be a worthwhile exercise to conduct.

Predicting invasions is a complicated science and even more problematic in the marine environment due to the difficulty associated with monitoring and detection. *H. americanus* has some traits that correspond with invasive characteristics like higher fecundity and moderate dispersal, but impediments to establishment also exist including low propagule pressure, lack of prior invasion success, and a similar predator profile as the native species. Establishment requires a reproductive population and there are many remaining uncertainties the reproductive success of either pure *H. americanus* individuals or hybrids (see Section 4).

**Section 3. Habitat and ecological considerations**

Ecosystem impacts of *H. americanus* colonization in European waters are likely dependent on the abiotic habitat constraints of the species associated with the ecosystem. Sea temperature and sea floor structure are two of the most important habitat requirements for *H. americanus*. From an ecosystem perspective, any *H. americanus* ecosystem impacts would likely be observed via changes in food web structure and species interactions through new prey, predators, and competitors the species would face in European waters. Thermal habitat requirements and the physical habitats required for *H.*
and *H. gammarus*, and possible ecosystem influences from a colonization, are reviewed here.

Temperatures influence critical biological rates (e.g. metabolism, consumption, growth, enzyme kinetics) that affect species survival. Thermal requirements of species ultimately define their thermal limits geographically and areas of suitable habitat. Water temperatures occupied by *H. americanus* generally range from 5°C to around 20°C (Aiken and Waddy 1986), although they can temporarily withstand temperatures as low as -1°C to as warm as 30°C (Harding 1992). Colder waters in the winter (6° to 8° C; Aiken and Waddy 1986, Waddy and Aiken 1995) provide proper temperatures for ovarian development and the synchronization of molting and spawning cycles (Waddy and Aiken 1995). Larval settlement is most successful in water temperatures of at least 12°C (Annis et al. 2013).

Differences in thermal tolerances at various life stages may pose an ecosystem advantage for one species over the other. There may also be differences in temperature tolerances between the species. For example, *H. gammarus* stage IV larvae require temperatures greater than 14°C to develop (Schmalenbach and Franke 2010), whereas *H. americanus* larvae are more cold tolerant and will develop through stage IV between 10°-12° C (MacKenzie 1988).

Because comparable climates are one of the few robust predictors of invasion potential, we compared the seasonality of thermal habitats between the Northwest and Northeast Atlantic to see if NE Atlantic waters were within the thermal tolerance of *H. americanus*. We calculated climatological mean winter minimum and summer maximum for coastal bottom waters over the past decade. For the Northwest Atlantic, we used the the Northwest Atlantic Regional Climatology from the National Oceanographic Data Center (NODC; http://www.nodc.noaa.gov/OCS/regional_climate/nwa-climate), constrained to the observed geographic distribution of American lobsters. The data from the NODC was based on direct observations of water column temperatures and was fairly comprehensive with only minimal imputation necessary. Bottom water temperatures for the Northeast Atlantic utilized the available reanalysis products from the Forecasting Ocean Assimilation Model 7km Atlantic Margin Model (FOAM AMM7) hydrodynamics model, available online from http://marine.copernicus.eu. Thus, the data for European waters is model-based but data-driven. Such models commonly have accuracy problems for bottom waters but this was the best, readily available data set for this analysis. For both regions, March and September had the lowest and highest temperatures, respectively, so were used for the winter minimum and summer maximum temperatures. With this data, we calculated the mean interannual winter bottom temperatures for each pixel by averaging across data from 2005-2012 for the NODC and 2005-2011 for FOAM AMM7 (Figure 1). Data for the NE Atlantic were further constrained to <=300m depths.

To compare thermal eco-regions between the study areas, we first delineated regions in the Northwest Atlantic using a spatial hierarchical cluster analysis based on winter and summer temperatures, then visually pared the clustering tree to a parsimonious level (Figure 2 and 3). To characterize each NW Atlantic eco-region, we calculated the centroids from the mean winter and summer temperature for all pixels within each region. We then matched data from each location (pixel) in the NE Atlantic to its nearest NW Atlantic centroid, based on euclidean distances (Figure 2B and Figure 3B). While this process matches every pixel in the NE Atlantic to its most similar NW Atlantic region, some NE Atlantic temperature combinations were relatively far from any NW Atlantic centroid and, therefore, potentially outside the domain of the NW Atlantic thermal regimes. We determined
appropriate domains for individual regions, based on the mean nearest-neighbor distance among NW Atlantic centroids (2.32 degree-units), and consider any NE Atlantic pixel greater than this distance from a centroid to be outside the domain of the NW Atlantic thermal regimes (Figure 2 and 3).

As a whole, water temperatures in the NW Atlantic are cooler than in the NE Atlantic but portions of the NW Atlantic included in this analysis, including the deeper portions of the Gulf of St. Lawrence, are considered too cold to be good lobster habitat. Waters off the north coast of France and south coast of England are near the upper thermal tolerance of *H. americanus* and correspond with inshore Southern New England habitats (region 3) where *H. americanus* currently appears to be experiencing thermal stress and recruitment failure. Much of the current landings of *H. americanus* in the NW Atlantic comes from regions 5-7 (the Gulf of Maine and Scotian Shelf), which corresponds to habitats observed around northern England, Scotland, and along the coast of Norway and Sweden. Much of the habitat around England could be considered "outside" of existing NW Atlantic habitats, based on our domain criteria, but this area is "thermally between" NW regions 1 & 4, which support lobster populations in moderate densities in the NW Atlantic.
Figure 1. Winter minima (top), summer maxima (center) and annual temperature change (bottom) in bottom waters for the geographic distribution of *H. americanus* off the east coast of North America (left) and the risk assessment area in western Europe (right). Color ramp indicates temperature (°C).

Figure 2. Defined eco-regions (a) within the *H. americanus* distribution off the east coast of North America based on temperature cluster analysis, (b) closest thermal habitats off the west coast of Europe, and (c) closest thermal habitats omitting "non-comparable" habitats (i.e. regions where the exact combination of winter and summer temperatures is not found in NW Atlantic). Color ramp indicates eco-region as determined by NW Atlantic thermal regime.
Figure 3. Biplot of winter minima vs summer maxima for each eco-region in (a) the NW Atlantic and (b) NE Atlantic data as assigned to nearest NW Atlantic eco-regions with representative 2.32 degree-diameter circles around regional centroids. Each dot represents a pixel from the maps in Figures 1 and 2. Dots outside the circles between regions 1 and 4 in plot b correspond to excluded areas in Figure 2c.
Over all life stages, *H. americanus* prefer structured habitat for shelter (see Lawton and Lavalli 1995 for review). However, habitat constraints are most evident during the settlement stage. *H. americanus* settlement is most common in shallow waters (<20m) with cobble substrate (Wilson 1999; Wahle and Steneck 1991). The cobble habitat provides ideal shelter for lobsters in their first years of life. Given this limited habitat in coastal areas (assuming a viable larval population under favorable oceanographic conditions), suitable settlement habitat has often been considered a bottleneck for recruitment, leading to variable recruitment success annually and demographically (Wahle and Steneck 1991; Wahle and Steneck 1992).

*H. gammarus* appears to also utilize cobblestone habitat (Linnane et al. 2000a), and likely has the same reliance on structured habitat for successful recruitment (see Mercer et al. 2001, Ball et al. 2001). Settlement densities are unknown in the field, after multiple attempts to locate newly settled *H. gammarus* have failed (Mercer et al. 2001). Several possibilities have been suggested to explain the inability to locate newly settled *H. gammarus* (early benthic phase, "EBP"), including low densities of the population in general, or that they utilize very deep crevices thereby avoiding capture by suction sampling devices (Linnane et al. 2000b, Mercer et al. 2001, Butler et al. 2006). Whether the difficulty finding EBP *H. gammarus* is related to low density, high predation rates, or inability to effectively sample makes it difficult to determine the availability of open niches for *H. americanus* settlers.

Larval transport away from nursery habitat has been shown to influence European lobster recruitment in the United Kingdom (Nichols and Lovewell 1987). Larval dispersal potential may be similar between the two species if *H. americanus* females are releasing larvae into EU waters, and will be dependent on the location where females hatch their eggs. The four larval stages of the two species are morphometrically very similar, although *H. gammarus* larvae are larger (Gruffydd et al. 1975, Carlberg et al. 1978). These morphological similarities imply that the larvae are similarly affected by ocean currents, and exhibit similar behaviors throughout the dispersal process. *H. americanus* larval dispersal is determined by both large and finer-scale oceanographic processes (see Xue et al. 2008, Incze et al. 2010), as well as larval swimming behaviors performed mostly by stage IV postlarvae (reviewed by Ennis 1995). Delivery of competent larvae to settlement habitat will not only depend on oceanographic transport and mortality that takes place in the water column, but on overall larval densities. Low reproductive European lobster populations (low spawning stock biomass) may limit reproductive output, reducing the numbers of larvae in the water column (Butler et al. 2006). Similarly, low numbers of *H. americanus* females introduced to the region would likely also result in low numbers of larvae released.

In contrast to the postlarval stages, post-recruit and adult *H. americanus* can travel significant distances annually (typically 20-30 km and up to over 90 km; Campbell and Stasko 1985, Campbell 1986) over various substrates (including eelgrass, sand, bedrock, and mud; Addison and Fogarty 1992, ASMFC 2014) utilizing depths between 4 and 100 m (with a maximum observed depth of 480 m; Holthuis 1991). Conversely, post-recruit and adult *H. gammarus* have been found in much shallower waters, including intertidal zones (Moland et al. 2011, Linnane et al. 2000b, Mercer et al. 2001, Galparsoro et al. 2009). Habitat suitability modeling for *H. gammarus*, based on capture in commercial pots in the Bay of Biscay, indicates that lobsters prefer depths ranging from 35-40 m in boundary areas between soft sediment and rocky-bottom, steep slope depressions, and areas where wave energy is moderate or significant (Galparsoro et al. 2009). *H. gammarus* also migrate far less (Moland et al. 2011, Agnait et al. 2007, reviewed in Butler et al. 2006), resulting in low gene flow in the population and even instances of
genetic subpopulations within 140 km of each other (Jørstad et al. 2004). Given the difference in movement patterns, low population densities and uncertainty regarding settlement habitat for *H. gammarus*, it’s unclear whether *H. americanus* and *H. gammarus* would occupy the same ecological niches and influence the ecosystem via similarities in habitat utilization.

*H. americanus* are often considered scavengers with a diverse diet. Prey taxa include mussels, gastropods, macroalgae, polychaetes, and amphipods (Sainte-Marie and Chabot 2001). Diets between the two clawed lobster species appear to be similar (Steneck and Wahle 2013). However, depending on the habitat used by these species, the degree of niche overlap or separation of the species is uncertain. Similar questions have been raised in Canadian waters focusing on *H. americanus* and rock crab *Cancer irroratus*. Coexistence between these two species has been attributed to different substrate use and food resources as they grow and increase in size (Hudon and Lamarche 1989). Further, Hanson et al. (2014) found that *C. irroratus* plays a more significant role as a conduit in trophic interactions in coastal ecosystems than *H. americanus* based on its diet, distribution, predator stomach contents, and abundance. Thus, similar diets and habitats alone do not provide sufficient information to determine the degree of prospective competition between the two clawed lobsters in European waters.

Both species have been observed competing for shelter during their respective mating seasons (Debuse et al., 2003, Karnofsky et al. 1989, Karnofsky and Price 1989, Stein et al. 1975). However, the degree to which this would occur due to shelter limitations is unclear, given the low densities of the native species. The fate of lobsters in inter- and intraspecific competition for space depends in part on the presence and diversity of predators. Subordinate lobsters in a predator-free region likely would be displaced to other habitats, but in the presence of predators, the carrying capacity of the system may impede population growth (Butler et al. 2006).

As primarily a coastal species, *H. gammarus* competes with a more diverse guild of predatory fish than that exists within the range of *H. americanus*, which may be in part why *H. gammarus* populations have been much lower than the western North Atlantic *H. americanus* population (Rick Wahle, personal communication). Competing and ecologically similar decapod crustaceans are also more diverse in the European waters than in North America. Such European crustaceans include crabs (cancrids, portunids, xanthids, porcelainlds), squat lobsters (galatheids), and snapping shrimp (alpheids), all inhabiting shallow rocky habitat (see e.g. Mercer et al 2001). Thus, the more complex European trophic level of decapod crustaceans may repress prospective *H. americanus* establishment.

Predators for *H. americanus* vary with distance from shore. Offshore predators include smooth dogfish, Atlantic cod, Atlantic halibut, wolffish, thorny and smooth skate, whereas inshore predators include shorthorn and longhorn sculpin, cunner, and white hake (Hanson and Lanteigne 2000, Butler et al. 2006, Boudreau and Worm 2010). Predation appears to be most significant at the northern (cooler) and southern (warmer) ends of the species latitudinal range (Boudreau et al. 2015). Changes in top-down controls of ground fish on lobster (i.e. predation) have been postulated for contributing to the observed abundance trends within coastal Gulf of Maine. Following the intense fishing pressure on cod and haddock in coastal Gulf of Maine in the 1930s, *H. americanus* abundance and landings increased and were sustained from the 1940s through the 1970s, and were then followed by extremely large increases since the 1990s (Acheson and Steneck, 1997, Steneck, 2006, Steneck and Wahle 2013). With taxonomically and ecologically similar predators inhabiting European waters, *H. americanus* population growth would likely be countered by a depensatory predation force.
Invasive species may alter commercial, recreational or aquaculture harvest (Hayes and Sliwa 2003). Ecosystem changes from *H. americanus* colonization could also be reflected by impacts to other commercially and recreationally important species. However, competition between species and other ecosystem changes are only one component influencing harvests. Social, cultural, and economic changes to a society will also influence fishing pressure on a stock, making it difficult to identify changes in commercial landings solely based on ecosystem impacts from possible *H. americanus* colonization. Understanding potential ecosystem and food web changes on fisheries has been attempted using modeling tools (e.g. Ecopath with Ecosim). However, such tools require data or knowledge on how the system works, and without a true quantitative understanding of how *H. americanus* would influence the native species’ essential habitat and resources, it is difficult to predict commercial and recreational impacts. Thus, it is uncertain how a *H. americanus* introduction to European waters would influence harvests on *H. gammarus* and other indigenous European species.

Section 4. Reproduction in *H. americanus* and potential hybridization between *H. gammarus* and *H. americanus*

Successful colonization of *H. americanus* to EU waters would require establishment of a reproductive population. However, determining whether mating between ‘wild’ *H. americanus* males and females is occurring in EU waters will prove difficult, primarily because *H. americanus* females can store sperm in their seminal receptacles for long periods of time. There is a considerable delay between mating and spawning in this species, so it is likely that females transported to the EU will be carrying viable sperm in their receptacles, and if they manage to escape, will be able to spawn fertile, pure-bred clutches. Detection of larvae, early benthic phase, or adolescent-sized *H. americanus* will be necessary to identify successful reproductive output in EU waters, regardless of whether the mating act took place in North American waters prior to capture and exportation, or EU waters. Whether there are surveys in place in EU locations that would be capable of detecting these size classes, which may not be available to the fishery due to gear selectivity, is unclear.

Introduction of sexually mature *H. americanus* may impact the reproductive success of the native *H. gammarus*, since the two species are congeners. Wasted time and energy spent in unsuccessful couplings with a partner of the wrong species, or successful production of hybrid offspring could decrease reproductive output of the *H. gammarus* population. *H. gammarus* appears to generally follow a 2 year reproductive cycle, producing one clutch every 2 years (Agnalt et al. 2007), thus there would be a lengthy reproductive ‘time-out’ associated with a failed mating or production of a hybrid clutch. The Swedish RA identifies a few instances of captured egg-bearing *H. americanus* that, upon genetic testing, were determined to be carrying hybrid clutches (3 of the eleven tested females captured from Norway or Sweden). This indicates that mating between female *H. americanus* and male *H. gammarus* has occurred in the wild. Whether this occurred due to active mate selection by the female, or due to lack of availability of *H. americanus* males, is unclear, although likely the latter. Also unclear is the degree to which this might continue to occur if the numbers of *H. americanus* increase. It will also be difficult to detect *H. gammarus* females carrying hybrid clutches, since in most locations ovigerous *H. gammarus* are not legal to harvest, and would be immediately returned to the sea by fishermen. Therefore, unless there is something visually striking about the appearance of hybrid eggs on *H.
H. *gammarus*, it doesn't seem likely that fishermen would set the female aside to have her clutch tested. Detection of *H. gammarus* females with hybrid clutches would require targeted survey efforts; this has taken place in the spring of 2010 and again in fall of 2012 with negative results (no hybrid clutches found on *H. gammarus* females) (A. Agnalt, IMR Bergen, Norway, personal communication, 2016), however there is no ongoing survey effort for this purpose. Without a basic understanding of normal mating behavior in *H. gammarus*, nor sufficient experimental evidence describing species-specific mate choice for either species, it is difficult to determine the degree to which the two species might be expected to interact sexually.

Reproductive behavior in *H. gammarus* is not as well-studied as *H. americanus* behavior, thus it is often assumed that the behaviors of the two species are similar. In one study where female *H. gammarus* were presented with a male of each species, all observed sexual interactions took place intraspecifically, regardless of the dominance status of the *H. gammarus* male (van der Meeren et al. 2008). *H. americanus* males were reportedly not interested in the *H. gammarus* females. Interestingly, mating in this study took place in only 5/15 trials, and nearly always when the female was in premolt stage (the authors reported premolt only generally as “Stage D”). One female mated just days prior to molting, then again after molting (48 hrs later). Presumably, as in *H. americanus*, any sperm deposited will be lost when the female molts, so these results are extremely counter-intuitive, and the implications are not clear. While the authors suggest that the study shows female *H. gammarus* distinguish between male *H. gammarus* and *H. americanus*, the mating activities observed may not have resulted in successful fertilization, thus leaving questions as to the underlying mechanism behind the behaviors observed. For example, while time spent shelter-sharing was highest between conspecific males and females, they also exhibited the lengthiest bouts of aggressive interactions (van der Meeren et al. 2008).

Intermolt mating may be more common in *H. gammarus* than in *H. americanus* (van der Meeren et al. 2008, Skog 2009), and may take place regardless of whether the female is already inseminated (Skog 2009). It is possible that intermolt mating in *H. gammarus* acts to suppress aggression by a dominant male, instead of primarily serving a reproductive purpose (see for example Thornhill and Alcock 1983, Rowe et al. 1994, Skog 2009). Thus it remains unclear whether female *H. gammarus* can and do distinguish between potential mates of the two species. There have been no studies examining whether female *H. americanus* can or will distinguish between males of different species. The geographic separation between the two very similar species may have prevented evolution of mechanisms to identify conspecifics.

Other researchers have observed mating between *H. americanus* and *H. gammarus* individuals in captivity, resulting in the production of fertilized hybrid eggs. Carlberg et al. (1978) presented male *H. americanus* with recently molted female *H. gammarus* (females molted in isolation, then were placed with the males), and observed 6 incidences of mating, followed by 5/6 females spawning clutches. Three of those females dropped their clutches, while two of them successfully hatched hybrid larvae. Talbot et al. (1984) also successfully produced hybrid individuals in the lab (again by pairing a *H. americanus* male with a *H. gammarus* female). They then used the adult hybrid females to attempt production of a second generation, mating the newly molted hybrid females (N=10) with *H. americanus* males. All of these females spawned and attached their eggs, but subsequently lost the clutches within a month. There have been reports of fertile hybrids produced by Japanese researchers, (reported in literature as personal communications with J. Kittaka); however the data have not been published.
The viability of hybrid lobsters produced by *H. gammarus* x *H. americanus* cross-breeding remains uncertain. Hybrid larvae have been demonstrated to survive and grow in laboratory environments, however the fertility of hybrids is unclear (see above). Carlberg et al. (1978) reported that hybrids produced by female *H. gammarus* mothers were similar in size to pure-bred *H. gammarus* larvae, and were generally larger than *H. americanus* pure-bred larvae (the eggs were also larger throughout development). Survival of the hybrid larvae was higher at 22°C than 18°C, which is more characteristic of *H. gammarus* larvae (*H. americanus* larval survival is better at lower temperatures; MacKenzie 1988). It is likely that the species of the female strongly influences the size of the resulting hybrid larvae (due to higher maternal investment in reproduction). Female *H. americanus* captured in Norway and Sweden had hybrid clutches, and larvae were successfully hatched at the Institute of Marine Research in Bergen, Norway. Some larvae reportedly exhibited some morphological abnormalities, but some have survived to adulthood and fertility testing is currently underway (A. Agnalt, Bergen, Norway, personal communication 2015). Survival of hybrids in the laboratory suggests that, if resources (food, shelter, etc.) are limited, these individuals would need to successfully compete with native species to survive.

Section 5. Lobster diseases and associated fauna

Sweden's risk assessment lists concerns about American lobsters introducing pathogens and fouling, or encrusting, organisms into European waters. Such concerns are understandable given past incidents where freshwater crayfish, imported from the US, carried a water mold (*Aphanomyces astaci*) that was transmitted to Scandinavia's noble crayfish (*Astacus astacus*, see Edgerton et al. 2002). Because the cuticle of many European species of crayfish is thinner than that of the American species, they were more susceptible to the pathogen, with widespread dispersal across Europe, and devastating effects on local populations that are still trying to recover (Holdich 2003).

Two diseases were specifically mentioned in the risk assessment: epizootic shell disease and Gaffkemia (*Aerococcus viridans* var. *homari*). Another pathogen, white spot syndrome virus, was mentioned in the media and the Great Britain risk assessment. These pathogens and their diseases are discussed separately below.

Shell Disease

One of the primary concerns of Sweden's risk assessment is shell disease, which is understandable given the attention Epizootic Shell Disease (see below) has received relative to the Southern New England lobster stock. Bacterial shell disease is a broad, catch-all term for a necrosis of the cuticle that is usually associated with chitinoclastic bacteria. It typically occurs at low levels in healthy populations of lobsters and crabs throughout the world including Europe (Shields et al. 2006). In fact, shell disease has been reported from *Homarus gammarus*; Roald et al. (1981) reported it in 12% of European lobsters sampled from Oslofjord, Norway, and the condition is quite common on the edible crab, *Cancer pagurus*, from UK waters (Ayres and Edwards 1982, Comely and Ansell 1989, Vogan et al. 1999). Shell disease is usually not fatal and is typically found on physiologically stressed individuals. The proximate cause of shell disease is bacterial necrosis of the cuticle, but the condition can have several ultimate causes that result from different stressors, such as poor diet, impoundment, contaminants, temperature, organic waste and nutrient overloading; and thus may be locally more
abundant in disturbed habitats (Shields 2013). The recent risk assessment includes accounts of American lobsters captured in European waters, one of which exhibited shell disease when captured, and several others that developed shell disease while held in aquaria. It is unclear from these reports what type of shell disease these lobsters exhibited. The condition has many different underlying etiologies that manifest as the shell disease condition. However, such diseases are commonly initiated or exacerbated by holding individuals in high stocking densities where abrasions in the epicuticle from physical contact with other lobsters in conjunction with poor water quality and an improper diet, allow for microbial infection.

Epizootic Shell Disease (ESD) is a bacterial dysbiosis that is most prevalent in inshore waters off the coast of New York, Connecticut, Rhode Island, and the south coast of Massachusetts (collectively referred to as Southern New England or SNE, ASMFC 2015). This region includes the southern extent of *H. americanus*’ distribution, where inshore summer water temperatures now commonly exceed the physiological tolerance of *H. americanus* for prolonged periods of time. ESD is generally not fatal but, in severe cases where extensive lesions form, it can kill the lobster or lead to early molting of the infected shell (Laufer et al. 2005, Stevens 2009). Although the SNE lobster stock has declined precipitously over the past two decades, this has been attributed to recruitment failure, partially due to a shift in lobster’s seasonal migrations in response to excessively warm waters (ASMFC 2009, 2010, 2015). Evidence also suggests that natural mortality has increased coincident with the warming trend (ASMFC 2015), and ESD along with other diseases identified in SNE lobsters may be contributing to this (Wahle et al. 2009, Shields 2013). Because of the small size of the SNE stock, lobsters from this region are generally consumed locally and not exported. ESD is much less common in the Gulf of Maine with low prevalence (<2%) and low severity in the cooler waters areas where most of the exports originate. Contrary to statements in the UK and Swedish Risk Assessment documents, no fishery in the U.S. has ever been closed in conjunction with ESD; the ASMFC Lobster Technical Committee recommended a moratorium due to the depleted condition of the stock and ongoing recruitment failure, not because of shell disease, but it was not imposed (ASMFC 2010, ASMFC 2012 Addendum XVII, available at: http://www.asmfc.org/uploads/file/amLobsterAddendumXVII_feb2012.pdf).

ESD is considered an environmental disease comprised of three parts: bacterial dysbiosis, increasing temperatures, and exposure to alkylphenols. The dysbiosis is a shift in the normal bacterial flora that occurs as a result of the other stressors. Multiple species of bacteria are found in ESD lesions, all of which are common and present on the shells of healthy lobsters from the same ecosystem (Shields et al. 2006). However, if the shell cuticle is breached, the bacteria can establish in the lesion and spread. Once established, bacterial growth and lesion progression are largely temperature mediated and are related to intermolt duration (Tłusty and Metzler 2012, Glenn and Pugh 2006).

One bacterium of particular concern for ESD is *Aquimarina homari*, which is recently described and poorly understood but common in marine sediments and crustaceans and may be a key player in ESD (Chistoserdov et al. 2012, but see Meres et al. 2012). *Aquimarina homari* is not capable of initiating lesions and there is no evidence of transmissibility between hosts (Quinn et al. 2012). Because it is common in marine sediments and invertebrates, it could be dispersed through multiple of vectors not limited to lobsters. However, it is not known whether *Aquimarina homari* is present in European waters.

Alkylphenols are a contaminant common in inshore SNE environments and have recently been linked with ESD (Laufer et al. 2012, Jacobs et al. 2012). Alkylphenols can function as an endocrine
disruptor that interferes with the hardening of the lobster shell after molting and thus increases the susceptibility of the cuticle to microbial infection (Laufer et al. 2012; Shields 2013). Alkylphenols are present in coastal waters in Europe including in Norway lobsters, *Nephrops norvegicus*, and stomatopods (Ferrara et al. 2005, 2008). The related alkylphenol ethoxylates were scheduled to be banned in Europe in 2000 (Renner 1997), and other alkylphenols have been limited there.

Finally, *H. americanus* has a thinner shell than *H. gammarus*, the reverse of the past situation with crayfish where the Scandinavian noble crayfish had the thinner shell, which suggests that *H. gammarus*, if infected with ESD, would be more resistant to the symptoms of the disease (Whitten et al. 2014). Because ESD is an environmental disease, it requires very specific conditions to fulminate. The bacteria associated with the condition require a portal of entry, are associated with other stressors, and are present on healthy lobsters; thus the risk ESD imposes on *H. gammarus* is likely to be low.

**Gaffkemia**

Gaffkemia is a bacterial disease caused by *Aerococcus viridans* var. *homari*. The bacterium is a common soil-inhabiting, Gram + coccus that can cause a highly virulent disease in lobsters under very specific circumstances. Low infection and mortality rates have been observed when *A. viridans* was experimentally injected into other crabs and shrimp. Similar to shell disease, infections require a portal of entry and are highly dependent on damage to the cuticle of the exoskeleton to gain entry. Mortality rates and time to death are dependent on temperature and lobster health. Gaffkemia has been reported in *H. americanus* from the Gulf of Maine and much of the Canadian Atlantic, although it may currently be on the decline (Basti et al 2011, Bouchard et al 2010). The bacterium is thought to have been introduced to Europe via the shipment of diseased *H. americanus* to Norway (Alderman 1996, Jørstad et al. 1999), but, there is some controversy about its occurrence there (Egidius 1972, 1978), and whether it has become established in natural populations. Within European waters, Gaffkemia has been reported in low levels in wild populations and has caused outbreaks in holding facilities in both Norway and the UK (Wilk et al. 1987; Nilsen 2002, Mortensen 2002, Stebbing et al. 2012). Thus, Gaffkemia has been present in European waters for more than 40 years.

Because it is a common soil bacterium, it is not clear if what remains in the environment are remnants of past introductions or simply background levels in existing populations. The bacterium proliferates in lobsters held at high stocking densities, but prevalence levels in holding facilities have declined significantly with improvements in water quality and shifting trade practices from pegging to banding lobster claws, which removed a major portal of infection. Infections in wild lobsters are rare, and have been reported at under 5% (Stewart et al., 1966) but normally lower than 0.1% (Keith et al., 1992; Lavallée et al., 2001, Bouchard et al. 2010 Stebbing et al. 2012). Past outbreaks were reported from holding facilities; there are no records of epidemics in wild lobster populations (Shields et al. 2006).

Given existing practices of banding claws, maintaining lobsters at cold temperatures, and proper regard for animal health, as well as the fact that the pathogen has a very low prevalence in wild populations and is present in European waters, the risk of an outbreak of Gaffkemia in *H. americanus* and *H. gammarus* is very low.
White spot syndrome virus

White spot syndrome virus (WSSV) is a significant viral pathogen of penaeid shrimp that is a host generalist in crustaceans. The virus has been mentioned in the news media in relation to the proposed embargo on American lobsters to Sweden. WSSV can cause disease in experimental infections of *H. americanus* (Clark et al. 2013), but it does not occur in natural populations of the lobster. The virus is a notifiable pathogen with respect to the international trade of crustacean products (World Organization of Animal Health, 2016). Frozen commodity shrimp imported from various locations are potential vectors for introduction of WSSV, and these frozen shrimp are reportedly utilized by recreational anglers in the UK (Bateman et al. 2012). Laboratory work has demonstrated transmission of WSSV to *H. gammarus* fed WSSV-infected shrimp (Bateman et al. 2012). WSSV has been reported from Europe and is listed as "non-exotic" in EC Directive 2006/88 (Stentiford and Lightner 2011). Thus far the demonstrated vector is imported shrimp products, not *H. americanus*.

Epibiota associated with *H. americanus*

There are various encrusting and fouling organisms that can be associated with *H. americanus*, including barnacles, sabellid polychaetes, tunicates and bryozoans, that permanently attach to the lobster’s shell (Bernier et al. 2009). We have not found information pertaining to how these epibionts on *H. americanus* relate to their host’s ecology, so have no way to know the impacts of transport and release of gametes from these organisms into foreign waters. However, one could argue that these organisms are similar to any that might attach to ships or have larvae found in ballast water. In addition, similar if not identical fauna can be found on *H. gammarus* (see Fernandez-Leborans and Tato-Porto 2000; Middlemiss et al. 2015).

Additionally, there is a known nemertean egg predator (*Pseudocarcinonemertes homari*) that resides in the lobster’s gills when immature and reproduces within the egg clutches of ovigerous females, resulting in loss of portions of the clutch (Aiken et al 1985, Brattey et al 1985). These worms have very specific patterns of egg predation that are not always associated with decreases in lobster fecundity. A bacterium, *Photobacterium indicum*, has been recently mentioned in the literature with regards to stressed lobsters, but is treatable with an antibiotic (Basti et al 2011). In addition, the is at least one parasitic copepod, *Nicthoe astaci*, found on *H. gammarus* that would likely parasitize *H. americanus* and possibly cause pathology through its blood sucking mouthparts (Davies et al. 2014). The larger concern may be associated with organisms that are currently unknown, or to which *H. americanus* has evolved resistance, that may be inadvertently transmitted into EU waters.

Section 6. Conclusions

Successful colonization and establishment of *H. americanus* into EU waters is plausible, but the probability of this happening is highly uncertain. Given the number of potential introductions of *H. americanus* into EU waters that have occurred over the last 50 years, and the fact that *H. americanus* has not yet become established, successful establishment seems unlikely. Introductions of individuals in small numbers, long generation times, larval and adult dispersal, potential exploitation by humans, and the potential for hybridization with *H. gammarus* should all impede the establishment of populations in European waters. Improved handling, knowledge or post-export animal care should resolve any
additional concerns on this subject. Detailed conclusions for each of the major identified concerns are listed below.

- **Is there available, appropriate habitat for adult *H. americanus*?** Yes, both structural and thermal habitat exists within the tolerances and preferences of *H. americanus*.

- **Can *H. americanus* successfully compete, or potentially outcompete, the native *H. gammarus*?** Uncertain. The only study to document competitive outcomes between congers had a small number of males, and generally the larger lobster was the dominant. More directed work is required to understand this issue.

- **There are several issues relative to reproduction:**
  - **Can *H. americanus* initiate a self-sustaining reproductive population?** Uncertain. There are likely to be density-dependent processes involved.
    - Arrival of gravid *H. americanus* females from North America allows these females to spawn pure-bred clutches using stored sperm.
  - **Can *H. americanus* individuals mate with *H. gammarus* and produce hybrids?** Yes, although the viability and competitive abilities of hybrid offspring remain uncertain.

- **There are several issues regarding larval recruitment:**
  - **Is there available, appropriate habitat for larvae (water column) and for settlers (benthos)?** Yes, appropriate thermal habitat for larval development and for settlement, and appropriate structural habitat for settlement, exist.
  - **Will larval dispersal deliver *H. americanus* larvae to appropriate settlement habitat?** Uncertain. This will be dependent on hatch location and oceanographic conditions.
  - **Can larvae and newly settled *H. americanus* survive?** Uncertain. There are many predators and potential competitors in settlement habitat, more so than in the native environment.

- **There were several disease-related issues identified:**
  - **Will introduction of *H. americanus* introduce Gaffkemia?** Gaffkemia is already present in *H. gammarus*, additional introductions are not likely.
  - **Will introduction of *H. americanus* introduce Epizootic Shell Disease?** Unlikely. Epizootic Shell Disease is not contagious, but is considered an environmental disease. However, there is uncertainty regarding the presence of the associated bacteria in EU waters.
  - **Will introduction of *H. americanus* introduce White Spot Virus?** Unlikely. Imported shrimp products are the identified vector for this virus, not *H. americanus*.
  - **Will introduction of *H. americanus* introduce unknown pathogens?** Uncertain.

- **Will introduction of *H. americanus* introduce associated epibiota?** Uncertain. However, it is unlikely to be a comparable risk as that associated with international shipping (ballast water, hull fouling).
Literature Cited:


Bernier, R.Y., A. Locke, and J.M. Hanson. 2009. Lobsters and crabs as potential vectors for tunicate dispersal in the southern Gulf of St. Lawrence, Canada. Aquatic Invasions, 4: 105-110.


A Preliminary Analysis of the Swedish Risk Assessment of American Lobster
(*Homarus americanus*) by the Department of Fisheries and Oceans, Science Sector

This preliminary analysis is based on the version of the Swedish Risk Assessment document dated Dec. 7, 2015.

**Introduction:**

Sweden has produced a risk assessment for American Lobster as a potential invasive species in their waters (see reference section for full citation). The below review represents a preliminary analysis of the scientific aspects of that risk assessment. Different conclusions could result from a science peer review that may be produced by DFO in the future.

**Background on risk assessments for non-native species:**

Non-native species can become invasive, so biological risk assessments are often used to characterize and assess the potential risks associated with such species. Many different frameworks exist that can be used to perform a biological risk assessment on a species. All of them aim to assess some common elements including: the likelihood that a species will be introduced into the new environment and the magnitude of the ecological consequences of that introduction. When referring to the issue of invasive species, the successful introduction of a non-native species into a new environment involves four parts: arrival, survival, establishment, and spread. ‘Establishment’ means that a species has arrived in the new environment, it was able to survive, adults of that species are reproducing successfully in the new environment, and a self-sustaining population is formed. The likelihood of introduction and the magnitude of consequences are then combined to produce an overall level of risk that is associated with the species. Risk assessments can be qualitative, quantitative, or some combination of the two. Robust risk assessments also incorporate uncertainty into the various elements used to generate the overall risk, or they assess uncertainty separately.

**Overall comments on the scientific aspects of the Swedish risk assessment and methodology:**

- A more comprehensive scientific review of the Swedish risk assessment for American Lobster requires information about the risk assessment framework or model that was used, and the methodology that was used to combine scores and assess and incorporate uncertainty. Any supporting documentation, tables, and scoring guidelines, etc. that were used to arrive at the final risk score are necessary to fully assess the conclusions that are presented in this risk assessment document.

- A key question that is central to any risk assessment for invasiveness is whether the species has been known to be invasive either in the risk assessment area or elsewhere in the world. In this case, the available evidence suggests that for American Lobster the answer is no, however the risk assessment does not seem to give sufficient weight to these key facts in the determination of overall risk:
  - **American lobsters have been recorded from European waters for many years (in some areas, over twenty years) yet there are no signs of establishment or invasiveness of the species in Europe (or elsewhere in the world).**
  - **Many attempts to introduce American Lobsters outside of their native range have been made including the west coast of North America and parts of Europe, but all have failed. In all cases there have been no signs of species establishment, let alone invasiveness.**

- Many one-sided arguments are presented regarding the risk of American Lobster as an invasive species in Europe, without considering alternatives. For example, disease transmission from American Lobsters to European Lobsters was cited as a significant risk in this assessment. It is argued in the assessment that
American Lobsters may be more susceptible to shell diseases than native European lobsters, and that they pose a risk of transmission to the native stocks. However, one could also argue that this susceptibility would leave American Lobsters at a disadvantage compared to European Lobsters, and could in fact be hindering them from establishing or spreading in Europe.

- The risk assessment relies heavily on qualitative evidence and it makes many unsubstantiated assumptions without providing studies to support them. There are several examples in the document where the likelihood of something occurring was stated as being ‘high’ or ‘very high’ with ‘high’ confidence, but then was followed with contradictory statements such as “it is difficult to comment on how likely…” (pg. 38).
- Hybridization between native European Lobsters and non-native American Lobsters is touted as a key negative impact and source of risk, however there is no clear evidence that hybrid lobsters can successfully reproduce in the lab, and none is presented to suggest that hybrids can reproduce in the wild. If they could survive and reproduce in the wild, there is no evidence that these potential hybrids would have any type of advantage over native lobsters (they could even fare worse).
- The risk assessment mentions that 13,000 metric tonnes of live American Lobster are imported to the EU per year, however the volume of imports into the risk assessment area (i.e.: Sweden) should be used. From this number, lobsters brought in and/or held near suitable habitat should be considered when assessing risk.

Comments on scientific aspects of the likelihood of introduction (arrival, survival, establishment, and spread):

Arrival:

Details about the probability of arrival of American Lobster into European waters is outside the scope of this preliminary scientific review, since arrival would likely involve aspects of industry practices, regulations, other vectors such as intentional release, etc. However, it should be noted that the specific holding requirements in lobster pounds in Europe were not discussed in the risk assessment document. Details about the level of containment required by importers would be required to fully assess the risk associated with the ‘arrival’ element through escape from lobster holding facilities. Another key piece of contextual information pertaining to arrival is the proportion of live lobsters imported compared to the number of American Lobsters that have been found in the wild in Europe.

Survival:

Suitable conditions (non-biological such as water temperature, salinity, etc...) likely do exist for American Lobster in parts of Sweden, however there is no evidence presented to suggest that American Lobsters can survive across the EU, or what would comprise their suitable habitat there. It is simply stated that temperatures are similar between eastern North America and Europe and that, given the ability of the American Lobster to live in a variety of conditions, it should be able to tolerate and thrive in Europe as a whole. Relatively small numbers of live adult American Lobsters discovered in certain parts of Europe does not necessarily mean that the species can survive in all other parts of Europe. Habitat differences across European waters surely exist, so habitat, or at least basic environmental parameters (e.g., water temperature), should be mapped to determine specifically where American Lobsters could likely survive in Europe. These are key questions that should be addressed. If suitable habitat in Europe is only localized to certain areas, then a continent-wide ban may not be supported by science.
Establishment

A key question remains to be clearly answered in this assessment using scientific support regarding the probability that American Lobsters can successfully reproduce in European waters. If the species cannot complete its life cycle in European waters then it cannot establish there, and therefore would not pose a threat. Life cycle completion would involve a male and female American Lobster encountering one another in the wild, mating in the wild, the fertilized eggs then developing into very young lobsters (larvae) and then juveniles, the juvenile lobsters surviving and growing into adult lobsters, and then these adults successfully mating to produce more lobsters. After decades of known introductions of American Lobsters into European waters, there are still no signs of successful reproduction in the wild or establishment. Some effort has been made to locate juveniles and nurseries in European waters, but so far no evidence has been found (Linnane et al. 2001, Ringvold et al. 2015). While there may be somewhat mixed opinions about whether establishment is possible or has already happened in Europe, given similar environmental conditions in parts of the European coast compared to the native range in North America, the risk would not be zero. However there is generally a lack of support presented in the Swedish risk assessment for the assertion that American Lobsters can establish in Europe.

Juvenile lobsters are not part of the North American lobster fishery (only adults are), so only adults are being exported. Therefore, the fact that juvenile American Lobsters have never been found in European waters supports the idea that American Lobsters are not completing their life cycle there and may not be capable of establishing. Given that reports of American Lobsters turning up in parts of the EU have been occurring for decades and there are fairly extensive trapping efforts associated with commercial and recreational fisheries, if American Lobsters were established one would expect that juveniles would be detected. Standard trapping techniques (e.g., lobster traps) would effectively sample for juveniles as well as adults. The risk assessment mentions female American Lobsters that were found in Europe with eggs; however this is not necessarily evidence of life cycle completion because females can store male sperm for over a year before producing fertilized eggs. In addition, American Lobster larvae require more specific environmental conditions than adults in order to survive and grow (e.g., specific temperatures, salinity, low pollution levels), which could hinder their establishment outside their native range. The habitat requirements of American Lobster larvae in their native range in North America are known, so these requirements could be compared to the average conditions in different parts of EU waters (e.g., the number of days per year with temperatures over or under a certain value) to help predict if, or where, American Lobsters might be able to complete their life cycle in Europe. Furthermore, there have been multiple attempts to introduce American Lobsters outside of their native range. Attempts have been made on the west coast of Canada, the west coast of the U.S., the Bay of Biscay in Europe, and in Japan. All of these attempts are considered to have failed. Page 29 of the risk assessment also states that: “H. americanus has also been deliberately introduced into a number of locations over the years, including the Pacific coast of American and Japan (Kittaka 1984) with the idea of stock enhancement (CABI 2013; van der Meeren et al. 2010), but with no success”. Even in west coast Canadian waters, despite multiple attempts at introducing the species, reproduction of American Lobster was constrained due to a parasite that affected them there, and all attempts at transplantation failed.

Spread:

The spread of American Lobster in European waters would only become an issue if the species becomes established (see above). If establishment did occur, then spread to new areas could potentially occur through human-mediated actions, such as ballast water of ships (transporting the tiny larvae) and the intentional and unintentional release of commercial sized adults (see Stebbing et al 2012). The ability of American Lobsters to spread through natural movements in European waters is suggested to be high (‘can migrate over long distances’) based on tagging studies of the American and European lobsters in their native environments. However, natural
movement rates of American Lobster are variable and thought to be habitat dependent. For example, Comeau and Savoie (2002) found that American lobsters in the southern Gulf of St. Lawrence in the Northwest Atlantic actually only moved relatively short distances (between 2 and 19 km). There is uncertainty regarding rates of movement of American Lobsters outside of their native habitat. There have been numerous reports of live adult American Lobsters from parts of Europe (e.g., Norway, Sweden, Denmark), but it would be useful to know how far these reports were from lobster holding facilities to help assess probability of spread and to provide more information on their habitat use once released. Page 46 presents the proportion of habitat in Europe that American Lobster can establish in, implying that some habitat suitability mapping or other quantitative analysis was performed. Future analyses would require access to maps or associated data that were used to generate these figures, as they were not included in the risk assessment document.

The ability for a species to spread has implications for its level of invasiveness, and as stated in the risk assessment on page 29, this does not seem to be true for American Lobsters: "H. americanus has not been found to have established viable populations outside of its native range, as to date". The report states that 26 live American Lobsters have been caught off the coast of the UK since 1988 and 29 have been confirmed off the coast of Norway since 2000. Yet despite multiple decades of known introductions, there are no signs of invasiveness of the species.

Comments on scientific aspects of the impact:

This risk assessment often refers to "massive" negative impacts of American Lobster with little more than speculation and qualitative statements to back it up. How is a score of "massive" calculated? Speculation regarding impacts in a risk assessment is acceptable when there is a lack of concrete supporting evidence, however the level of certainty in those circumstance should be 'low' or 'very low'. Yet in this risk assessment confidence surrounding impacts is stated as being 'medium'. Similarly, implying that American Lobster could have impacts such as a decrease in tourism to watch fishermen land native lobster at the docks (pg. 32) is very far reaching and unsupported (would such tourists be able to distinguish among local fisherman who are landing native versus non-native lobsters?). Generally, the impact section of the assessment tends to blend potential ecological and socio-economic impacts together with considerable uncertainty around both. It is also somewhat one-sided that the potential scenario of an increased catch/market value that could come along with American Lobster establishing in Europe is never considered. If this scenario was realized, as shown by the introduction of king crab to the Barents Sea, it could support a profitable fishing industry (Windsland 2015).

Specific aspects of impact that were primarily focused on in the Swedish risk assessment were: the potential for hybridization between American lobster and European Lobster, the potential for competition between the two species for resources (e.g., food, suitable habitat), and the transmission of disease and other 'hitchhiking' organisms from American Lobster to European Lobster.

**Hybridization:**

Hybridization occurs when individuals of two different species are able to mate and produce offspring, either in the wild or in a lab setting. These offspring can then be sterile (i.e.: cannot successfully reproduce themselves) or fertile (i.e.: capable of successfully reproducing). Hybridization could be of concern if hybrid American-European Lobsters are created and are able to survive in the wild, they could potentially have traits (e.g., physical, behavioral) that give them a competitive advantage over native lobsters. There appears to be mixed scientific evidence for the potential mating and hybridization of American Lobster with European Lobster, either in the lab or in the wild.

4
Female European Lobsters have been shown to preferentially select male European Lobsters over male American Lobsters for mating in lab studies (van der Meeren et al. 2008). The possibility of hybridization between the two species has been supported by some lab-based studies and by lobsters sampled from the wild. Hybridization between European and American Lobsters has been achieved in the lab (Calberg et al. 1978, Hedgecock et al. 1977). Hybrid eggs have been shown to develop normally in the lab and have been reared there for up to one year (Calberg et al. 1978), however it remains to be seen if they would survive in the wild. The confirmation of hybrid eggs either in the lab or in the wild would confirm that members of the two different species can successfully breed. However, it does not necessarily mean that those hybrid eggs would then be able to grow normally in the wild into adults who then successfully reproduce themselves. Hybrid offspring would need to be able to reproduce themselves in the wild in order to pose any threat. The risk assessment does not present evidence that hybridized eggs can do this, but some literature exists about the subject. For example, some studies report that female hybrid lobsters are usually fertile (meaning they produced eggs themselves) but that male hybrid lobsters may or may not be fertile (e.g. Carlberg et al. 1978, van der Meeren et al. 2008, Stebbing et al. 2012). Other lab studies (e.g., Waddy & Aiken 1985) showed that most female hybrid lobsters lost most of their eggs before they hatched and that the sperm of hybrid males tended to be sterile. This suggests that lab-reared hybrid lobsters may not be as robust as native lobsters and says nothing about whether hybrid lobsters could survive and establish in the wild, let alone out-compete native lobsters for resources. Female American Lobsters bearing hybrid eggs were found in Norway and Sweden (i.e., A.-L. Agnalt pers. comm. in Stebbing et al. 2012; Hauge et al. per comm.), which does support the possibility of American and European Lobsters mating in the wild. However, these reports have not been vetted through an external scientific peer-review process and do not provide the details of the procedures or techniques that were used to arrive at their findings. If hybrid eggs are created, their ability to survive in the wild in European waters, grow into adult hybrid lobsters, and then these adults successfully reproduce themselves still needs to be determined. Hybridization could be actively tested for in individuals from high risk areas (e.g., Gullmarsfjord, Sweden). The genetic techniques exist to do this and have been applied to other species to address this question (Bradbury et al 2014; Bradbury et al 2015).

Competition:

Based on the current body of scientific literature very little is known about any competitive advantages between American Lobster and European Lobster. There is no evidence presented in the risk assessment that suggests that American Lobsters can survive across the EU, or what their relative habitat requirements are compared to those of the European Lobster. In fact, the risk assessment states: "...no evidence of ecologically negative consequences is found in the field".

If hybrids were found to be able to survive and reproduce in the wild, then the ability of hybrids to out-compete native lobsters for food and space during each life stage would also need to be addressed to adequately assess the risk for impact from hybridization.

The assessment presents the idea that American Lobster eggs might hatch earlier in the season than European Lobsters giving American Lobsters a competitive advantage. There is no supporting evidence presented for this assertion and the opposite could be equally as true: depending on variation in environmental conditions and resources from year to year, it could actually be a disadvantage to have earlier hatching eggs.
Disease and hitchhikers:

Disease

Gaffkemia is a bacterial disease that can affect the shell of lobsters. It is present in both North American and European waters (Greenwood et al. 2005), and has been present in Europe since the 1950's (Egidius 1972). It only becomes a problem if the lobster's shell is damaged, otherwise it remains inactive. Some important characteristics about this disease were not adequately considered in the Swedish risk assessment. For example, American Lobsters with this shell disease typically do not make it to market because of their poor outward appearance and therefore are not likely to be exported. Also, lobsters that have the shell disease often won't have the disease present on their shell after moulting (periodic shedding of the shell to reveal a newly grown one). Some evidence suggests that Gaffkemia may have initially been transferred to Europe by American Lobster imports. There is mixed evidence regarding how severely the disease affects European lobsters, and differences in severity may occur in the lobster pound compared to the wild. The bacterium has been reported since the mid-1950s when outbreaks in lobster pounds were resulting in high mortality (Roskam 1957). However, despite the long history of reports of introduction, a recent study showed a low prevalence of Gaffkemia in European Lobsters in England and Wales (Stebbing et al, 2012) where less than 1% of the population was infected with the shell disease and the individuals carrying the disease appeared to be healthy. Another study (Wiik et al (1987)) found that less than 0.1% of wild European Lobsters in Norway were infected after looking at over 3,000 animals. The high level of impact Gaffkemia on European Lobster that is suggested in the Swedish risk assessment is not supported by the literature as conflicting reports have been published (Wiik et al. 1986; Snieszko and Taylor 1947; Roskam 1957). Despite this uncertainty, a statement was made in the risk assessment that “disease could enhance the ability of American Lobster to establish due to a certain disease resistance”, yet no references were provided so this may be speculation. Furthermore, the body of the document mentions epizootic shell disease (ESD) as a potential limiting factor to American Lobster: “a recent study indicates that H. americanus may be more susceptible to ESD than H. gammarus (Whitten et al. 2014), although there is a need of further investigations.” This risk assessment was using this, and other studies, to argue that because American Lobsters may be more susceptible to shell diseases than European Lobsters, this poses a risk to native lobsters. However, one could also argue that this susceptibility would leave American Lobsters at a disadvantage compared to European Lobsters, and could in fact be hindering them from establishing or spreading in Europe. Recall that previous stocking efforts on the west coast of North America failed in part due to American Lobsters being affected by diseases that were present in those new areas that they had never been exposed to. Similarly, the risk assessment did not address the possibility that European Lobsters could potentially transmit diseases to the non-native American Lobster. In the same way that a disease from North America could leave the native European stocks at a disadvantage, a disease from European waters could leave any introduced American Lobsters at a disadvantage in Europe.

Regarding the risk associated with other diseases, the Canadian Food Inspection Agency (2013) has determined that white spot disease is not currently found in Canada. As for Epizootic Shell Disease (ESD), it has only recently been identified as the bacterium Aquimarina homaria (Quinn et al. 2012) and is likely not the only causal agent (Sweet and Bateman 2015).

Hitchhikers

The risk assessment suggested that some larger, more visible organisms (e.g., barnacles) could hitchhike their way to Europe on American Lobsters and be introduced into the wild in Europe where they could become invasive. However, no specific species were identified in the risk assessment. Each of these species would need to be identified in order to independently assess their true risk (i.e.: likelihood of their introduction and magnitude of
Moreover, some of the suggested hitchhikers may already be found in the EU and it would be useful to know if any of them have a history of being invasive elsewhere in the world. The qualitative, generic statements presented in the risk assessment regarding the potential for hitchhikers do not provide the detail necessary to fully assess this aspect of risk.

**Conclusion:**

In conclusion, the methodology used for this risk assessment, and the supporting documentation for how the individual risk scores were combined and how uncertainty was assessed will be necessary to perform a thorough scientific review of this risk assessment and its conclusions. This is a preliminary review from a scientific perspective, and did not address industry practices, and regulations, or enforcement. There are many aspects that were touched on here that may be elaborated upon in a more fulsome review.

**References:**


