4: The Eroding Foundation of the Food Web

Diporeia

A healthy food web is a complex interrelationship in which each plant and animal benefits from and contributes to the success of the ecosystem. Typically the bottom of a food web begins with the tiniest creatures and their populations are endlessly bountiful. Moving up the food web, the animals become larger and their populations become fewer in number as they require more space and food. The top of the food web is very dependent on the health of all of the lower levels. When there is a disruption in the lower food web, negative effects ripple up through many populations and can be devastating.

A key part of the food web in the Great Lakes are macroinvertebrates (small animals without backbones) which link algae with fish communities. In particular in the deeper water of the lakes, four groups of organisms dominate the macroinvertebrate community — fingernail clams, certain worms (*Oligochaetes*), opossum shrimp (*Mysis*), and most significantly, a tiny shrimp-like amphipod called *Diporeia*. Together, these organisms constitute the vast majority of the deepwater food available to forage fish and other animals the Great Lakes, accounting for as much as 99% of the biomass available in the sediments.[72] Any changes to the sediment environment that affects these organisms therefore has the potential to greatly affect the fish and other predators reliant on this food source.

Diporeia

Diporeia

Diporeia, particularly compared to other invertebrates, are an especially important, high-energy food source for many fish.[73] In fact, most fish species feed on *Diporeia* at some stage of their life cycle.[74] In deeper water habitats, *Diporeia* consume nearly one-quarter (23%) of the total annual production of phytoplankton[75] and, in Lake Michigan, they consume over 60% of the spring diatom bloom (blooms of an algae rich in lipids, another nutrient),[76] making these nutrients available to move up the food web.

Yet *Diporeia*, a key component of the Great Lakes food web, has dramatically declined over the past 20 years – in some cases decreasing from over 10,000 organisms per square meter to virtually zero. The scale and short time frame of the declines are particularly disturbing; fish species reliant on *Diporeia* need to find other equally nutritious food sources in order to survive in areas where the amphipod is in steep decline. If some of those food sources are less easily digested or available, the species would not likely be able to evolve characteristics quickly enough to compensate (see discussion in Section 5 on impacts of *Diporeia* declines).

Box 5

Locking up production in the lakebed: expansion of mat-forming bacteria

At the same time that *Diporeia* disappeared in Lake Ontario, a bacterium called *Thioploca* began to form in unusually extensive mats and soon became the most dominant organism in the sediments of the upper lakebed. More energy began being used in the development of bacterial mats, leaving fish and other resources useful to humans deprived of nutrients.[77] While some exotic species such as alewife can be viable food sources for commercial and sport fish species, bacterial mats do not provide food or habitat for these species. As the mats developed, the lakebed community was reduced to a few species of worms and a few tiny clam species. Additionally, nitrate has doubled in Lake Ontario over the past several decades,[78] which may also support the spread of the bacterial mats. Prior to 1991, dense *Diporeia* populations (up to 16,000 individuals per square meter[79]) probably directly and indirectly — by keeping the lakebed more oxygenated — reduced the development of the bacterial mats on the lakebed.[80]

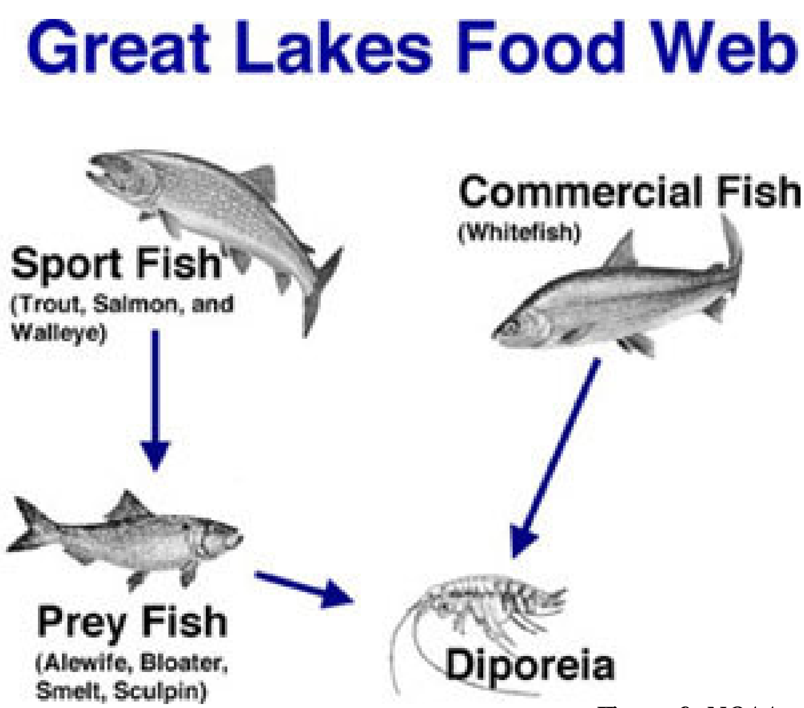


Figure 9: NOAA

Zebra mussels

Disappearance of high quality food coincides with the appearance of exotic mussels

Since their discovery in the Great Lakes, zebra and quagga mussels have colonized a wide variety of underwater surfaces to depths of 130 meters[81] and have reached densities of up to 340,000 per square meter in some areas.[82] Zebra and quagga mussels are aggressive and efficient filter-feeders that consume large volumes of nutrients, dramatically decreasing suspended nutrients that are critical to other species.[83] In particular, this diversion of food resources may deprive *Diporeia* and other deeper water macroinvertebrates of food settling from the above water.[84]

Substantial declines in *Diporeia* populations, as well as that of fingernail clams, have been observed in several of the Great Lakes since the establishment of zebra mussels. Although the connection between zebra mussel invasion and significant *Diporeia* declines coincides in time, direct causal links have not been clearly established. Although other potential explanations for the declines have been proposed – including decreasing algal nutrient resources and indirect competition with zebra mussel colonies in shallow water – these alone cannot explain the total elimination of *Diporeia* from favorable habitats.[85] Other factors that may affect *Diporeia* include disease from pathogens[86] — though none have been reported in the literature, as well as additional factors — yet unknown.

As *Diporeia* disappears, the pressure will be greater on a less abundant food source, the opossum shrimp. If the opossum shrimp is susceptible to the same factors that are causing the degradation in *Diporeia,* few other alternatives are left to support many fish and other aquatic animals in deeper waters of the Great Lakes. Indeed, scientists have observed impacts on fish that depend on *Diporeia* as a food source:

- In Lake Erie, smelt stocks have declined since the loss of *Diporeia*;
- In Lake Ontario, slimy sculpin and young lake trout, species that also rely on *Diporeia*, have declined;
- In Lake Michigan, whitefish have shifted from eating *Diporeia* to the more abundant, but less nutritious zebra mussel, leading to leaner, smaller whitefish.[87]

Fingernail Clams: As devastating as the disappearance of *Diporeia* may be for the Great Lakes fishery, it may be only part of a broader decline near the bottom of the food web. Scientists have also discovered what looks like a parallel depletion in another species, the fingernail clams. These clams are found in the upper sections of sediments and feed on microorganisms in the water between sediment particles. Because some fingernail clams filter-feed directly on algae, zebra mussels can be in direct competition with them for food. Research in Lake Michigan revealed substantial declines in fingernail clams through the mid-1980s and into

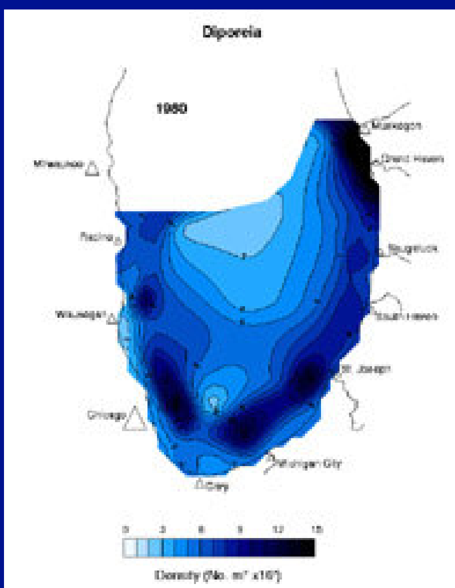
Fingernail clam

Diporeia in Lake Michigan: Examples of Declines in these Lakebed Food Resources

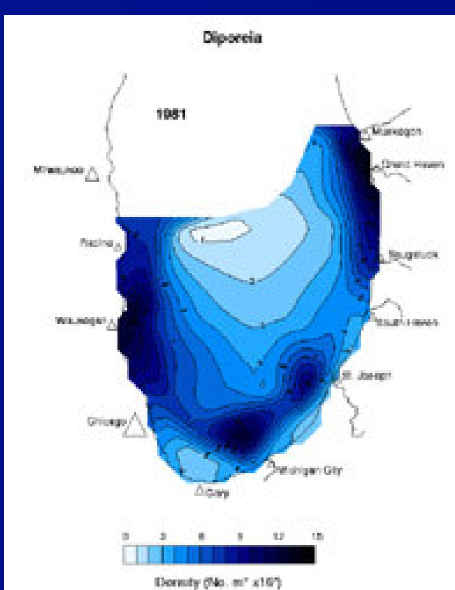
Diporeia numbers in southern Lake Michigan dropped slightly during the 1980s, but decreased much more rapidly beginning in the early 1990s following the introduction of zebra mussels to the lake in 1989.[88]

- The density of *Diporeia* at the Grand Haven, MI station dropped from 10,000 per square meter in the 1980s and early 1990s to 110 per square meter in 1999 after zebra mussels were discovered in the area in 1992 – a 99 percent decline.[89]
- The mean density of *Diporeia* off Muskegon, MI declined from 5,569 per square meter to 1,422 per square meter.
- By 1998, *Diporeia* declined in southern Lake Michigan and were rare or absent off Grand Haven, Saugatuck, South Haven, and St. Joseph out to depths of 70 meters.[90]

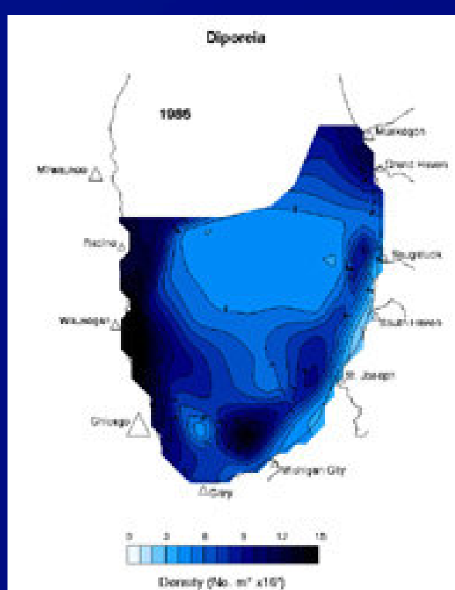
Figure 10: Changes in abundance of Diporeia in sediments of southern Lake Michigan from 1980-2000. By 1998, large sections of nearshore waters in the southern and southeastern portion of the lake were supporting few if any numbers of the shrimp-like organism. (Graphic from T. Nalepa, Great Lakes Environmental Research Laboratory, NOAA)



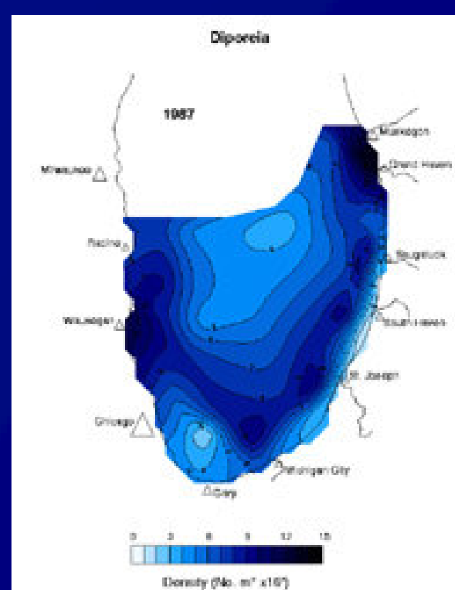
1980



1981



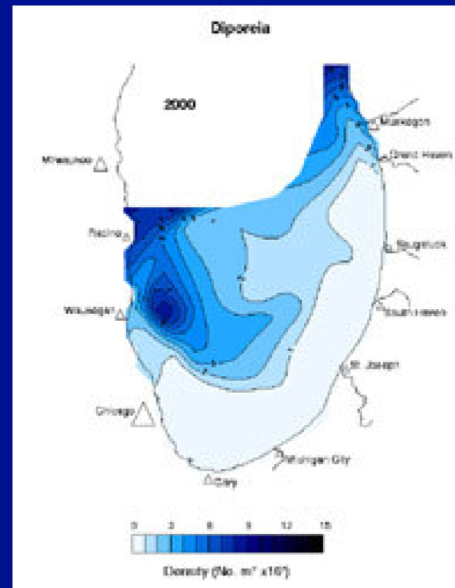
1986



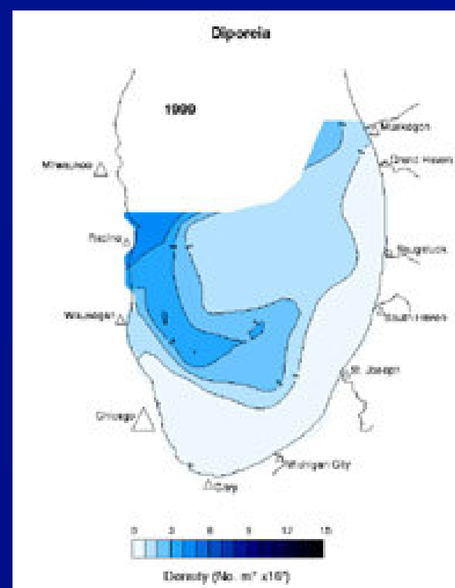
1987

Similar changes in *Diporeia* populations have been observed in sampling of a number of sites in Lake Ontario:

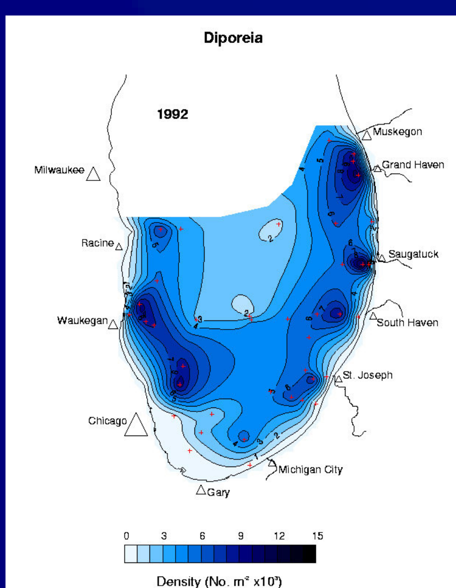
- Mean densities of *Diporeia* were at least 130 times greater in 1964 and 1972 than in 1997 after zebra mussel establishment.
- At locations where *Diporeia* was abundant, densities dropped to 15% of their former levels in three years (averaged 6,363 per square meter in 1994 and only 954 per square meter in 1997).
- The percentage of stations where no or very few *Diporeia* were found more than doubled from 40% in 1994 to 84% in 1997.
- A zone of very low *Diporeia* density (less than 4 individuals per square meter) extends as far as 16 miles (26 kilometers) off-shore and to depths of 656 feet (200 meters) over 40% of the total surface area of Lake Ontario soft sediments in 1997.



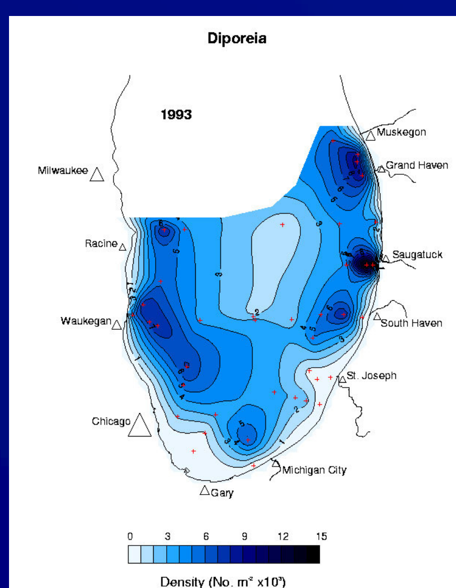
2000



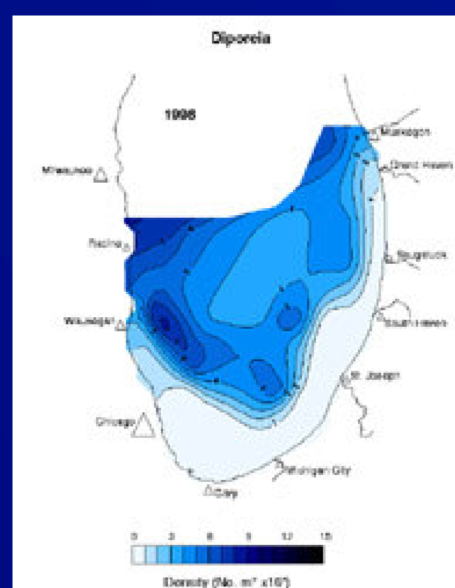
1999



1992



1993



1998

the early 1990s; yet the widespread nature of the declines – including beyond areas of zebra mussel infestation – suggested that zebra mussels may have had a more minor role, with nutrient reductions and declining primary productivity playing a larger role.[91]

However, in another study near Michigan City, Indiana, growth of zebra mussels on fingernail clams was observed, and the researchers hypothesized that zebra mussel colonization caused the significant declines in fingernail clams seen from 1992-1997, from a median of 832 to13 clams per square meter.[92] Similar results have been found in Lake Erie, where the clams declined significantly in areas where zebra mussels were abundant.[93] In western Lake Ontario, a significant increase in the population of zebra mussels was accompanied by a complete crash of two species of fingernail clams.[94] (See Figure 11).

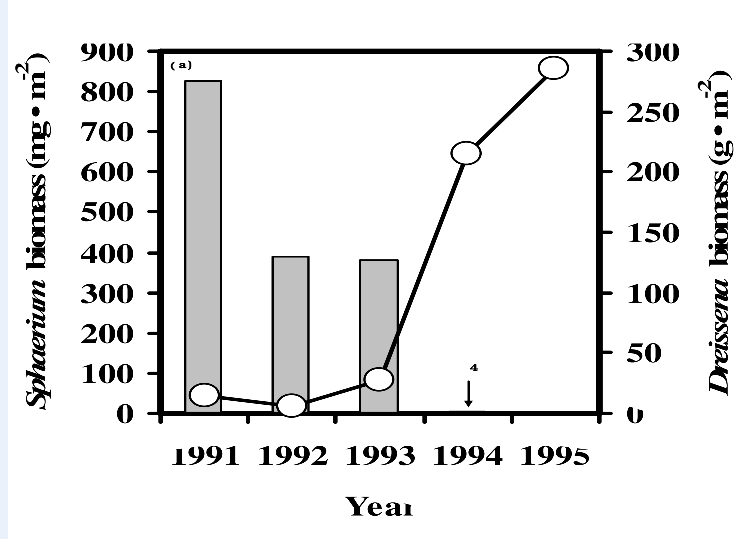


Figure11: *The introduction and expansion of zebra and quagga mussels (Dreissena) (open circles) near the mouth of the Niagara River corresponded with a steep decline in numbers of the native fingernail clam (Sphaerium) (bars) from 1991-1995.* (*Mills et al., 2003*)

Because fingernail clams can be important food sources for certain fish (for example, these clams were among the food items encountered most frequently in the diet of lake whitefish in southern Lake Michigan in the late 1990s),[95] reductions in their numbers could lead to additional foraging pressures on fish that consume them, in particular if zebra mussels are not eaten.

Another Species that May Be at Risk – Opossum Shrimp

Another important component of the food web is the opossum shrimp. This organism, which can grow up to about 1.5 inches long, feeds on a variety of zooplankton, and can move up and down through the lower, cooler waters of a lake.[96] It is an important food source for a number of fish species in open lake waters, including forage fish such as deepwater sculpin, smelt, alewives, and bloaters, as well as lake whitefish.[97] Research off of Muskegon, Michigan in southern Lake Michigan found that as the percentage by weight of *Diporeia* in the diet of lake whitefish declined from 70 percent to 25 percent from 1998 to 1999-2000, the intake of opossum shrimp increased from four percent to nearly one-third of the total.[98] Although research has yet to find declines in opossum shrimp populations, increased predation by fish that would otherwise feed more on *Diporeia* could lead to substantial pressures on these shrimp populations.

The dramatic decline -- to the point of disappearance -- of these foundation species represents a sea-change in the food web and the entire Great Lakes ecosystem. Although the causes have not been conclusively proven, scientists believe that invasive species -- particularly zebra mussels -- are the likely culprits. Regardless of the causes, we already are seeing substantial damage ripple throughout the Great Lakes fishery, as discussed in the next section.

Opossum shrimp