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Chapter 24

Concluding Remarks: Forecasting the Future of Oneida Lake and Its Fishery in an Era of Climate Change and Biological Invasions

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Forecasting the Future of Oneida Lake

Scientists are increasingly asked to do ecological forecasting, a task that requires us to understand the mechanisms involved in the interactions between physics and biology, in the interactions among species, and in the interactions among land use, human behavior, and drivers of management actions. Clearly, ecological forecasting spans many disciplines. Further complicating ecological forecasting are the continuous changes in the main actors driving systems as new species invade and priorities for human use evolve. In this concluding chapter, we will indulge in more speculation than typical for a scientific paper. With 60 years of data, we will attempt to forecast the future of Oneida Lake and its fishery with special attention to climate change and likely future invaders. Although the predictions are specific to Oneida Lake, the approach and some of the predictions are likely relevant to other lakes as well.

The future of Oneida Lake and its fishery is affected by factors that are outside the control of local citizens and managers of New York State. This is true for climate change and for the intercontinental movement of exotic species, processes that will only respond to global policy changes. Other factors can be controlled locally, such as fisheries regulations, fish stocking, land use practices, water level control, shoreline development, efforts to prevent the spread of new species across the landscape, and directed control of species already present be they native (e.g. double-crested cormorant *Phalacrocorax auritus*) or invasives (e.g. Sea Lamprey *Petromyzon marinus*, water chestnut *Trapa natans*). Local management strategies can mitigate unwanted changes and/or promote adaptations to these changes. Whether change is seen as negative or positive for Oneida Lake will depend on the interests of particular stakeholder groups and is not the focus of this chapter. However, conflicts between stakeholder groups over which management strategies should be implemented may affect future management decisions. In recent years, there has been a debate between angler groups interested in Walleye (*Sander vitreus*) and angler groups interested in Smallmouth Bass (*Micropterus dolomieu*) and Largemouth Bass (*Micropterus salmoides*, referred to collectively as black bass) as related to proposed changes in fishing regulations. There has also been disagreements about water level management between angler groups promoting fishing and shoreline property owners more interested in protecting their properties from flood events.

We will start our forecasting with climate change. Our predictions of climate change effects include an increase in summer water temperatures by up to 4°C by the end of the century and a decrease in duration of ice cover (DeStasio et al. Chapter 13; Hetherington et al. 2015). Trends over recent years support these predictions with a significant increase in average July–August water temperatures of almost 2°C since 1975 (Figure 1). This is a faster increase than most climate change models predict. Water temperatures in 2011 were similar to expectations for the year 2050 (Hetherington et al. 2015). Indeed, the northeastern USA is an area with faster increases in lake water temperatures than in other areas of the world (Sharma et al. 2015). The duration of ice cover has also declined, although this trend is more variable and strongly influenced by individual winters (e.g., 2013–2014 and 2014–2015 were cold in upstate New York and resulted in relatively long ice durations (Figure 1). Our predictions of future hydrodynamic changes in Oneida Lake also include a more extended period of stratification when the bottom waters of the lake are isolated from the surface (Hetherington et al. 2015). Based on these predicted changes in the physics of the lake, what predictions can we make about the lake's ecology and fishery?

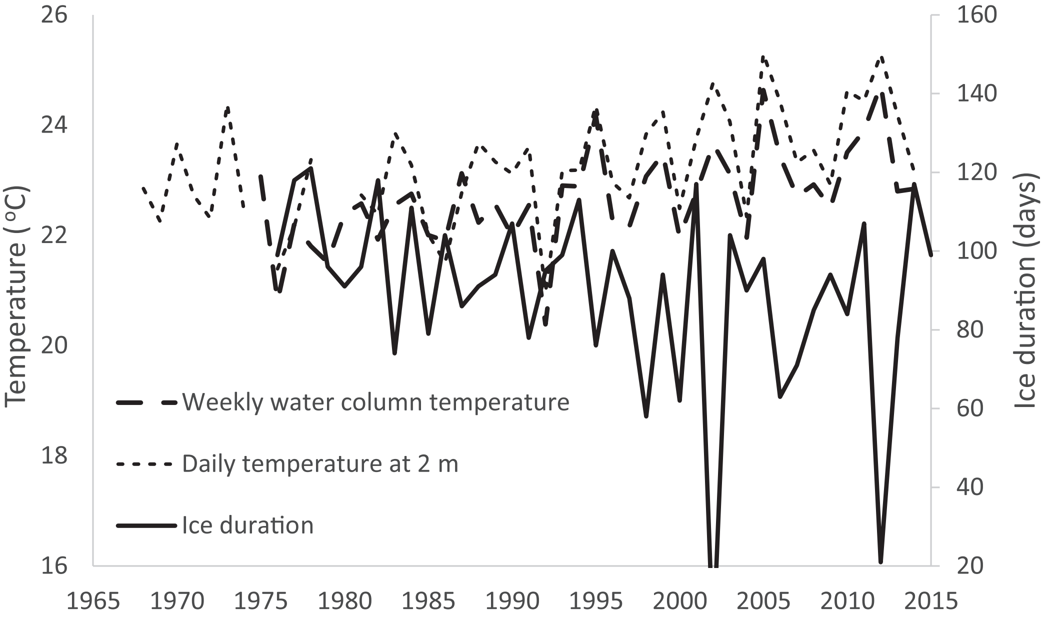

Figure 1. Summer (July–August) average whole water column temperatures calculated from profiles taken weekly at 4 stations across the lake and from daily measurements at 2 m depth at the temperature buoy at Shackelton Point, and ice duration in days since 1975. The increase in summer temperature is highly significant with an increase of 0.4°C per decade for this time period ($R^2 = 0.28$, $P = 0.004$, $N = 40$ for water column temperature and $R^2 = 0.26$, $P = 0.0005$, $N = 43$ for the temperature at 2 m depth). The decline in ice duration is marginally significant with a decline of 6 d per decade ($R^2 = 0.096$, $P = 0.052$, $N = 40$). Data in Rudstam (2015), Rudstam and Jackson (2015b) and in unpublished files (2-m temperature data).

Warmer summer temperatures have larger effects on fish communities in shallow lakes like Oneida Lake than in deep lakes because shallow lakes are polymictic—the whole water column mixes several times a year, thereby eliminating any cool water refuge for fish that are negatively affected by warm temperatures. Therefore, we expect that the remaining cold water fish—the Burbot *Lota lota*—will be extirpated from Oneida Lake this century (Jackson et al. 2008; Hetherington et al. 2015). It is doubtful that this fish will be missed by anglers. But with current warming trends, the lack of a cold water temperature refuge could become a problem for Walleye in the future. Temperatures around 24°C are above the physiological optimum for Walleye, and at those temperatures, consumption and condition factors decrease (Momot et al. 1977; Kocovsky and Carline 2001; Wuellner et al. 2010). Average July–August water column temperatures went above 23°C in only 2 of the first 20 years of the data series (1975–1994), compared to 10 of the years between 1995 and 2014, with average temperatures over 24°C in two of these latter years (Figure 1). At 2 m depth, average July–August temperatures exceeded 24°C in 10 of 20 years since 1995. On the other hand, black bass and other centrarchids are warmwater fish that do well in temperatures up to 30°C (Rice et al. 1983). We have already observed increases in both black bass species in Oneida Lake (Irwin et al. Chapter 18; Jackson et al. 2015a). Elsewhere, such increases have been associated with declines in Walleye although it is uncertain if this decline is a direct effect of competition between black bass and Walleye, or the response of ecosystem changes promoting bass over Walleye (Johnson and Hale 1977; Robillard and Fox 2006; Wuellner et al. 2011). Thus, based on expected increases in summer temperatures, we predict that black bass will increase and Walleye will decrease in importance through this century. This is already happening as Smallmouth Bass catches have increased and Walleye catches are below the long-term average. As a result, a larger proportion of the piscivore (Walleye + black bass) catches in our standard gillnets consisted of Smallmouth Bass in the 2000s (Figure 2).

With declines in winter severity and ice cover it is likely that more southern fish species with currently high over-winter mortality rates (Gizzard Shad *Dorosoma cepedianum*, White Perch *Morone americana*, Alewife *Alosa pseudoharengus*) will increase (Ridgway et al. 1990; Fitzgerald et al. 2006; Fetzer et al. 2011; VanDeHey et al. 2014). The Gizzard Shad is undergoing a northward range expansion throughout North America (Fetzer et al. 2011; VanDeHey et al. 2012; Fitzgerald et al. Chapter 23), which is likely the result of both higher summer growth in warmer temperatures and better over-winter survival during shorter winters (Fetzer et al. 2011). Note that winter severity may be non-linearly related to the length of ice cover. This is because Oneida Lake is coldest just before ice formation, after which the ice will insulate the water. Temperatures under the ice often increase during the winter through ground water influx. Thus, a lake with intermittent ice cover could maintain temperatures close to zero for longer time periods than a lake with solid ice cover and Gizzard Shad are more sensitive to 1 and 2°C (pre-ice formation temperatures) than to 4°C (under ice temperatures) (Fetzer et al. 2011). Nevertheless, when winter air temperatures become sufficiently warm to preclude ice formation (as predicted by the end of this century, DeStasio et al. Chapter 13), the duration of the period with stressful cold water temperatures will decline and sensitive species like Gizzard Shad, White Perch, and Alewife will survive the winter better and build up a higher adult biomass in the lake. Although short term predictions are uncertain, we are more confident that all three species will increase in the lake in the longer term.

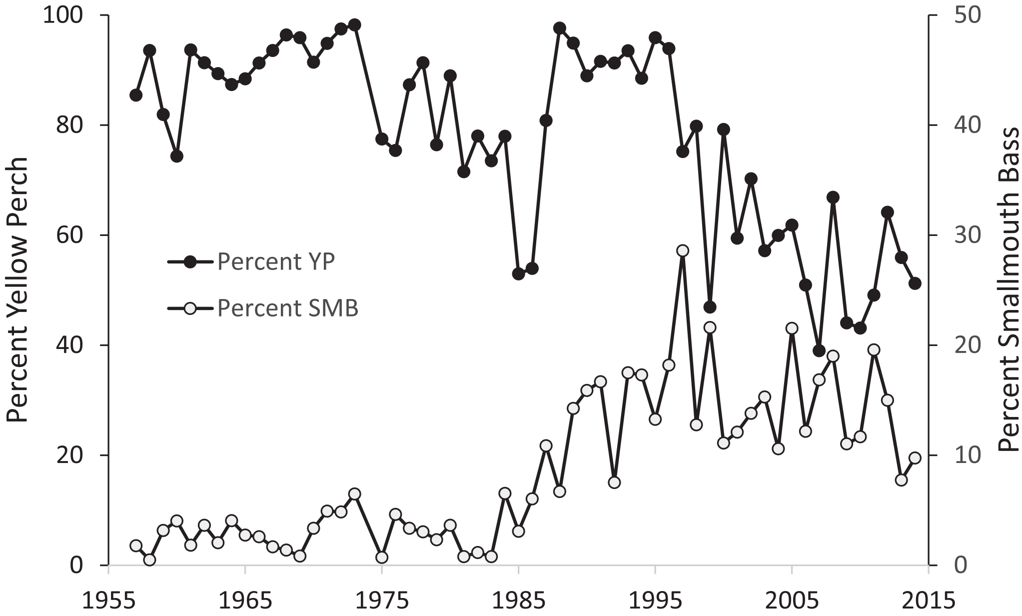

Figure 2. Percent of the total "perch" catch (Yellow Perch + White Perch) that consisted of Yellow Perch (Percent YP) and percent of the predator catch (Walleye + black bass) that consisted of Smallmouth Bass (Percent SMB) in Oneida Lake standard gillnet catches from 1957 to 2014. The decrease with time in the percent Yellow Perch ($R^2 = 0.46$, $N = 57$, $P < 0.0001$) and the increase with time in the percent Smallmouth Bass ($R^2 = 0.56$, $N = 57$, $P < 0.0001$) are highly significant. Data in Rudstam and Jackson (2015a).

The predicted effects of these three species on the lake ecosystem are different. Adult Gizzard Shad are benthivore/detritivores and their main effect would be increased turbidity through resuspension of sediments, increased nutrient recycling, and increased production of age-0 Gizzard Shad which already are an important component of Walleye and black bass diets (Vanni et al. 2006; Lantry et al. 2008; Wuellner et al. 2010; VanDeHey et al. 2014). In some states, Gizzard Shad are even introduced to reservoirs as forage fish for Walleye and bass (Noble 1981). In Ohio reservoirs, abundant age-0 Gizzard Shad can decrease recruitment of other fish species, in particular centrarchids like Bluegill (*Lepomis macrochirus*) through competition for zooplankton (DeVries and Stein 1992; Stein et al. 1995; Garvey and Stein 1998). However, effects on recruitment of other species are not found in all systems (Pope and DeVries 1994; Jackson and Noble 2000) and in Oneida Lake, Gizzard Shad are an important prey for Walleye and black bass and have buffered mortality of other forage species through the winter (Fitzgerald et al. 2006). Gizzard Shad have had no effect on age-0 Yellow Perch *Perca flavescens* growth even though Shad can crash *Daphnia* populations in late summer (Roseman et al. 1996). Abundant age-0 Gizzard Shad decrease the vulnerability of Walleye to angling (VanDeValk et al. 2005, Chapter 17) and could reduce fishing mortality. Adult Gizzard Shad increase nutrient recycling and may therefore increase algal blooms in the lake (Vanni et al. 2006). As we predict high abundances of both adult and age-0 Gizzard Shad in the future, we expect both positive (increased growth of predators, increased over-winter survival of age-0 Yellow Perch and Walleye) and negative (decreased catch rates) effects for the Walleye fishery and negative effects for water quality (increased nutrient recycling and turbidity).

White Perch may compete effectively with Yellow Perch as they feed on similar prey items (Fetzer 2013; Mills et al. Chapter 6; Fitzgerald et al. Chapter 23) and White Perch have been implicated in declines of White Bass *Morone chrysops* in both Lake Erie and Oneida Lake (Madenjian et al. 2000). In our gillnet data, the percent of the combined Yellow and White Perch catches that consists of Yellow Perch has declined in the 2000s (Figure 2) as catches of White Perch have increased and catches of Yellow Perch declined. This suggests a negative effect of White Perch on Yellow Perch. However, as with Gizzard Shad, there is no evidence of a negative effect of abundant age-0 White Perch on age-0 Yellow Perch growth rates, and adult Yellow Perch growth rates have not declined. Instead, the opposite occurred in the past—a negative effect of abundant age-0 Yellow Perch on age-0 White Perch growth rates (Prout et al. 1990; Mills et al. Chapter 6). Thus, the main negative effect of White Perch on Yellow Perch, and likely Walleye, are probably through White Perch predation on the larvae of the two percid species (Fetzer 2013). We observed that Yellow Perch early mortality increased with higher water clarity in Oneida Lake and elsewhere (Rudstam et al. Chapter 16; Manning et al. 2014) suggesting increased predation on larvae. White Perch do feed on larval Yellow Perch in Oneida Lake (Fetzer 2013). Since this mechanism would affect both Yellow Perch and Walleye, we predict declines in both those species as a consequence of an increase in White Perch. Although we cannot attribute changes in the Oneida Lake fish community to White Perch to date (Mills et al. Chapter 6; Fitzgerald et al. Chapter 23), the higher water clarity since the zebra mussel invasion is likely to increase the effect of the growing White Perch population. Water clarity is correlated with increased age-0 percid mortality in Oneida Lake (Rudstam et al. Chapter 16).

Alewife is a third species likely to benefit from milder winters. Age-0 Alewives have been caught in Oneida Lake in low numbers since the 1960s and grow well in the lake (5 age-0 Alewives caught on September 17, 2013 ranged from 112 to 135 mm), but have apparently not survived the winter as we have not yet caught a confirmed age-1 or older Alewife in the lake. This is in contrast to the high abundances of Alewife observed in several other nearby New York lakes (Wang et al. 2010; Rudstam et al. 2011). Even so, we do expect that Alewife will become abundant in Oneida Lake in about 30 to 50 years, and when they do, we expect this species to have a strong effect on the lake. Alewife will cause a shift in the zooplankton of Oneida Lake towards smaller-bodied taxa, such as *Bosmina* and small cyclopoids, which decrease water clarity as small zooplankton are less efficient filter feeders (Brooks and Dodson 1965; Cáceres et al. Chapter 11). Fewer large zooplankton will likely decrease growth rates of juvenile planktivores such as White Perch and Yellow Perch. Alewife feed on percid larvae (Mason and Brandt 1996; Brooking et al. 1998; Madenjian et al. 2008) and have been implicated in thiamine deficiency of salmonids (Fitzsimons et al. 1999) which may also affect Walleye. Walleye recruitment has decreased dramatically in several New York lakes following Alewife invasions (Rudstam et al. 2011; Brooking et al. 2016) and no stocked Walleye larvae survived in Cayuta Lake, a small lake with high Alewife abundance (Brooking et al. 1998). Therefore, Walleye larval survival is likely to decline dramatically in the lake if Alewife become abundant, and the Walleye population may have to be maintained by stocking fingerlings. This is the case in several smaller New York lakes with high Alewife abundance (Conesus, Cayuta, and Owasco lakes) and was the case in large systems like Saginaw Bay, Lake Huron, when Alewife was abundant in that lake (Fielder et al. 2007). As Alewives have access to Oneida Lake through the canal system, prevention of an Alewife invasion is not feasible. It may be possible to control Alewife through predator stocking, and there are examples where predators are believed to have caused a collapse of Alewife (Lake Huron, He et al. 2015; Otsego Lake, W. Harman, SUNY-Oneonta, personal communication). However, a seven-fold increase in standard stocking rates of Walleye did not result in a collapse of the Alewife population in Cayuta Lake, New York, and Alewife increased from very low numbers despite a high adult Walleye abundance in Canadarago Lake, New York (Rudstam et al. 2011). Both of these lakes are more productive than Lake Huron and Otsego Lake and therefore may be more predictive of the future of Oneida Lake.

There are possible mitigating management actions. If the Walleye population declines, and clupeid fishes (Gizzard Shad and Alewife) become abundant, Walleye growth rates will increase (Porath et al. 2003; Rudstam et al. 2011) and these larger, better fed Walleye will be harder to catch (VanDeValk et al. 2005). A trophy fishery could therefore be developed and maintained with restrictive size and creel limits to protect the lower Walleye population. In addition, black bass would continue to thrive and may show increased growth rates as these fish both feed on clupeids, and as nest guarders, are less likely to exhibit negative impacts due to larval predation by White Perch and Alewife. Thus, our predicted responses to an increase in Alewife would be declines in Walleye and Yellow Perch abundance, increased growth rates of black bass and Walleye, and decreased water clarity.

A third prediction of our hydrodynamic analysis of likely climate change scenarios is a longer period of stratification when the bottom waters of the lake are isolated from the surface (Hetherington et al. 2015). This could have larger effects on the lake than increases in temperature alone, but is affected by winds and the timing of storms (more frequent and stronger storms during the summer would mix the lake more often), factors that are harder for climate scientists to predict than temperature. If there is no concomitant change in wind patterns compared to current conditions, we expect that the lake will be stratified for longer periods by the end of the century. This would result in the bottom water layer going anoxic due to decomposition of organic material and the resulting biological oxygen demand. Under anoxic conditions, phosphorus that is bound in ferrous oxides in the sediment is released to the water column (Wetzel 2001). At the next storm event, this phosphorus is mixed back into the water column and could feed cyanobacteria (blue-green) blooms (Mooij et al. 2005). Such blooms were common during the early, more eutrophic periods of the lake (1950s and 1960s) and have continued to occur in late summer in most years (Idrisi et al. Chapter 9). During the summer (July–August) we have already observed both increases in the number of stations with low oxygen in the bottom waters for the whole data set and an increase in total phosphorus concentrations since 1996 (Figure 3). There is also a significant positive correlation between the proportion of stations with low oxygen and the average total phosphorus in the lake for the July–August period (statistics in Figure 3). Several of the Oneida Lake cyanobacteria are toxic (Hotto et al. 2008) and these toxins can impact zooplankton and fish (Schmidt and Jónasdóttir 1997; Malbrouck and Kestemont 2006). Beaches on the lake have closed in several of the recent years following blooms. In addition, cyanobacteria do well at higher temperatures. The release of phosphorus bound in the sediment will not occur if the lake mixes often, for example due to more frequent and intense storm events predicted in some climate change scenarios. However, these events will also increase phosphorus input through increased runoff from the watershed. Therefore, we predict cyanobacteria blooms will increase through this century. Better land-use practices and waste-water treatment may be able to mitigate the problem associated with runoff but are not likely to affect sediment phosphorus release because of the large amounts of phosphorus typically present in lake sediments of eutrophic lakes like Oneida Lake (Cuhel and Aguilar Chapter 7).

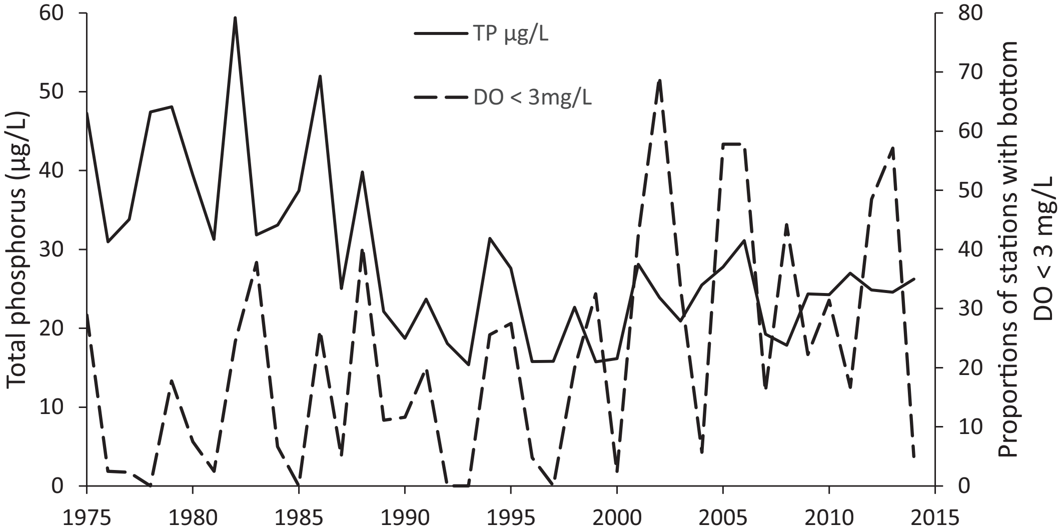

Figure 3. Average total phosphorus (TP) in the water column during July and August and the proportion of stations sampled in July and August with bottom dissolved oxygen values less than 3 mg/L, 1975–2014. The proportion of stations with low oxygen has increased significantly over time at a rate of 7% per decade ($R^2 = 0.20$, $N = 40$, $P = 0.0046$). There is a significant decline of TP over the whole data set ($R^2 = 0.34$, $N = 40$, $P < 0.0001$), but TP has started to increase again since the low value recorded in 1996 ($R^2 = 0.29$, $N = 19$, $P = 0.018$). There is also a significant correlation between the proportion of stations with low oxygen and TP since 1993 ($R^2 = 0.22$, $N = 19$, $P = 0.042$). Data in Rudstam (2015).

Another likely prediction is that new species will colonize the lake. Oneida Lake is connected through canals to both the Hudson River system and the Great Lakes system and therefore vulnerable to invasions from both directions. In Chapter 6, Mills et al. list the exotic species that had arrived as of 2012 and discuss Sea Lamprey, White Perch, and dreissenid mussels in more detail. Public awareness programs and better pre-transfer cleaning of recreational boats, a likely vector for spreading invasive species, can prevent or at least delay some invasions, but will have less effect on fish species that disperse actively on their own through the canal system. For example, Round Goby *Neogobius melanostomus* arrived through the Erie Canal. This species was found in nearby Onondaga Lake in 2011, reported by anglers at the west end of Oneida Lake in 2013 and spread throughout Oneida Lake by the fall of 2014 (Jackson et al. 2015a). Several other exotic species are close to entering the Great Lakes, in particular the Asian carp species Silver Carp *Hypophthalmichthys molitrix* and Bighead Carp *Hypophthalmichthys nobilis*, two species with potential to affect the Oneida Lake ecosystem (Chapman and Hoff 2011; Wittman et al. 2015). Another Asian carp, the Grass Carp *Ctenopharyngodon idella*, is already reproducing in Lake Erie (Chapman et al. 2013). In addition to these exotics, North American species not currently in the lake could arrive through range expansions and may affect the lake and its fishery. Several such species arrived in the last half century, including the previously discussed White Perch and Alewife. One other such example is the double-crested cormorant that caused an increase in sub-adult percid morality and contributed to the decline of Walleye and Yellow Perch in the 1990s (Rudstam et al. 2004). The current management of cormorants on the lake largely mitigate negative effects and is discussed in more detail in Coleman et al. (Chapter 19).

Of all these new species, the arrival of the zebra mussel *Dreissena polymorpha* in 1991 had particularly large effects on the lake, and they are discussed in several chapters in this book (Mayer et al. Chapter 9; Fitzgerald et al. Chapter 10; Cáceres et al. Chapter 11; Irwin et al. Chapter 18). Mussels affect the lake by filtering phytoplankton thereby clearing the water, allowing more benthic production and moving pelagic energy to the benthos, and by changing the structure of the bottom through their shells; a process given the name benthification (Mayer et al. 2014, Chapter 9). Around 2006, a relative to the zebra mussel, the quagga mussel *Dreissena rostriformis bugensis* arrived to Oneida Lake. The quagga mussel can colonize softer substrates than the zebra mussel and now are found at all depths of Oneida Lake. Quagga mussels can therefore build up a larger population in the lake than zebra mussels and have replaced zebra mussels in many lakes (Karatayev et al. 2014a). In Oneida Lake, the quagga mussel has been the dominant species since 2009. All the effects of zebra mussels listed above and documented through the chapters of this book are therefore likely to be amplified by quagga mussels. High water clarity in the spring will increase macrophyte coverage and increase mortality of early-hatching pelagic fish larvae, as observed for Yellow Perch and Walleye since the arrival of zebra mussels (Rudstam et al. Chapter 16). We therefore predict further increases in the area covered by macrophytes (Zhu et al. 2006; Fitzgerald et al. Chapter 10) which would benefit species like Largemouth Bass and Chain Pickerel *Esox niger*. We also expect continued high mortality of early hatching fish larvae like Walleye and Yellow Perch. Thus the ecosystem changes associated with dreissenid mussels, similar to the increased summer temperatures discussed above, are expected to be positive for black bass and negative for Walleye and Yellow Perch. Interestingly, dreissenid mussels have caused the extirpation of several native unionid clams from the lake, but not the extirpation of other mollusks as the number of native snail and clam species found in a lake-wide survey in 2012 has increased since the 1960s and was similar to the number of species found in the early 1900s (Karatayev et al. 2014b). This could be caused by the return of several native plant species to the lake (Fitzgerald et al. Chapter 10), likely the result of increased water clarity caused by the dreissenids. Mussels certainly are problematic because they clog water intake pipes and attach to boats and docks, causing high cleaning costs, and large amounts of shells on beaches decreases the recreational value of these areas. Mussel related nutrient regeneration may also increase (Hecky et al. 2004; Turner 2010) potentially contributing to algal blooms. But at the same time, increased water clarity increases shoreline property values (Limburg et al. 2010).

Round Goby feed on mussels, and prefer quagga mussels over zebra mussels (Kornis et al. 2012; Naddafi and Rudstam 2014). As Round Gobies are likely to become very abundant in Oneida Lake, we expect some decline in dreissenids in general and in quagga mussels in particular. Declines in dreissenids have been observed after Round Goby invasions elsewhere (Barton et al. 2005; Wilson et al. 2006; Lederer et al. 2008). Round Goby are aggressive and will likely decrease the abundance of smaller benthic fish in Oneida Lake, such as Trout-perch *Percopsis omiscomaycus*, Log Perch *Percina caprodes*, Mottled Sculpin *Cottus bairdii* and Tessellated Darter *Etheostoma olmstedi*. Round Goby will be an important prey species for black bass, Yellow Perch, White Perch, and Walleye and likely will increase growth rates of these sport fish, but also decrease angler catch rates. Gobies are also preferred prey of cormorants (Coleman et al. 2012; Johnson et al. 2015) and cormorant control may not be needed when Gobies (or Shad) become abundant (DeBruyne et al. 2013). Given the irreversible changes in the lake associated with dreissenid mussels, the effect of Round Goby is likely mainly positive as they represent a vector for moving energy bound in mussel biomass to the sportfish of interest to anglers. Potential negative effects include increased predation on fish eggs. However, there has been no negative effect of Round Goby on Smallmouth Bass populations in Lake Erie (Steinhart et al. 2005; Jackson et al. 2015b).

Another benthic fish that is now present in the lake is Lake Sturgeon *Acipenser fulvescens*, a species actively promoted through stocking and harvest protection in Oneida Lake. Lake sturgeon was re-introduced in the lake through stocking of 5,000 age-0 fish in 1995. The first natural reproduction was documented to have occurred in 2011 as a 2 year old naturally produced fish was caught in our standard sampling in 2013 (Jackson et al. 2015a). Sturgeon feed on mussels and have excellent growth rates in Oneida Lake (Jackson et al. 2002). Although Round Goby may cause some decline in mussels, Lake Sturgeon will likely feed on Round Goby, and we expect continued good growth of Lake Sturgeon. We therefore predict Lake Sturgeon will continue to thrive in Oneida Lake.

Not all new invasive species are equal and only a limited number of them have strong effects on ecosystems. For example, two exotic species that were studied intensively at the Cornell Biological Field Station were found to have limited impacts on the lake. The European frog-bit (*Hydrocharis morsus-ranae*) is a floating leaf plant similar to some native *Potamogeton* but with a white flower. Although the plant can form dense mats in protected areas (Zhu et al. 2008), it is also consumed by native herbivores and has no negative effects on benthic invertebrates (Zhu et al. 2015). Other exotic plants could be more problematic, including water chestnut, which is already in the lake but kept at relatively low numbers through citizen actions, the starry stonewort (*Nitellopsis obtusa*), which is increasing in abundance in the lake, and *Hydrilla*, which is present in Cayuga Lake despite large efforts to control the species and could potentially colonize Oneida Lake. The other species we studied intensively is the bloody-red shrimp (*Hemimysis anomala*), an up to 12 mm long mysid shrimp that arrived in Oneida Lake in 2009 (Brooking et al. 2010). This species is an omnivore that feeds on plant material but is also a voracious predator on zooplankton (Halpin et al. 2013; Sun et al. 2013). Although mysids can affect zooplankton communities (Rudstam 2009), this species is also a preferred prey of a variety of fish species and is not likely to become abundant in other than rocky areas where it can hide from predators during the day (Boscarino et al. 2012; Walsh et al. 2012). This species has spread through Oneida Lake, eastward into the Erie Canal, and it is moving towards the Mohawk River (Brown et al. 2014).

Another process that makes ecological forecasting difficult is that rare native species, some of which were once common in the lake, could increase as the lake ecosystem changes. One such species with potential large indirect effects is the large mayfly *Hexagenia limbata*. This species was reduced to non-detectable numbers in the 1960s and has started to increase in the 2010s. A return of the species to high abundance occurred in Lake Erie in the 1990s (Krieger et al. 2007). This mayfly is an important prey item during emergence in the spring and buffers Walleye predation on age-0 fish (Forney 1980; Mills et al. Chapter 6). We predict this would lead to stronger year classes of both percids (Forney 1980, Rutherford and Rose Chapter 20). A negative is that bioturbation by *Hexagenia* may also increase phosphorus release from the sediments (Chaffin and Kane 2010). Other native species that we predict will increase are warmwater and littoral fish species such as the two black basses and Chain Pickerel. These three predators could affect the existing fish community. We already discussed the black bass—Walleye interactions. Chain Pickerel is a sit-and-wait predator of the littoral zone and could be an important predator on young Walleye and Yellow Perch. Increased

Northern Pike and Smallmouth Bass populations are suspected contributors to declines in young Walleye survival in Milles Lac, a classic Walleye lake in Minnesota (Venturelli et al. 2015). At least four other native species that have a more southern distribution (Lee et al. 1980) have increased in recent years in our fish surveys—Bowfin *Amia calva*, Longnose Gar *Lepisosteus osseus*, Yellow Bullhead *Ictalurus natalis*, and Green Sunfish *Lepomis cyanellus*.

Other species will arrive, and some of them will likely have large effects on the lake. The Silver Carp and Bighead Carp have become very abundant in the Mississippi River drainage and three Bighead Carp were caught in Lake Erie between 1995 and 2000 (Great Lakes Fisheries Commission Lake Erie Committee). These species are planktivores throughout their life and will compete with other planktivores like Emerald Shiner *Notropis atherinoides*, Alewife, and young percids. As age-0 fish, the two carps will also be prey for Walleye and other piscivores. We predict the effects of these two species to be similar to that of Alewife as they will decrease large zooplankton abundance and therefore increase phytoplankton in the lake (Zhao et al. 2013; Zhang et al. 2016). However, these effects are uncertain because the carp are filter feeders that also consume phytoplankton and may be able to control cyanobacteria (Radke and Kahl 2002; Attayde and Hansson 2001). In addition, the Asian carp will not likely have the same negative effect on larval fish as we predict for Alewife, as they are filter-feeders and do not actively search for larger prey like fish larvae. Grass carp is reproducing in Lake Erie (Chapman et al. 2013) and may impact aquatic macrophytes if it arrives in Oneida Lake.

The mechanisms affecting the future of Oneida Lake discussed above are sometimes contradictory, further complicating ecological forecasting. Take for example the predictions of future water clarity, which in turn affects the extent of macrophytes and the importance of the littoral food web and littoral fish species. Quagga mussels are predicted to further increase water clarity whereas an increase in Gizzard Shad would decrease water clarity. The effect of longer summer stratification would increase internal nutrient loading and therefore increase phytoplankton, especially cyanobacteria, and may cause quagga mussel die-offs in deep water due to oxygen depletion, further decreasing water clarity as filtration rates decline. Our predictions are that the dreissenid mussels will maintain high abundance in the lake even with the possible declines of deeper populations and the increase in predation from Round Goby. The positive effect of mussel filtering on water clarity will be higher than the negative effects of increasing Gizzard Shad populations. Therefore, we predict water clarity will remain high during the spring and early summer. However, during the summer, the nutrient input from frequently anoxic bottom waters and/or from runoff due to increased and more intense storms will cause cyanobacteria blooms. Because this does not happen until later in the year, macrophytes will expand in the spring and early summer and colonize larger areas of the lake resulting in improved conditions for particularly Largemouth Bass and Chain Pickerel. Largemouth Bass will also benefit from increased water temperature whereas Walleye and Yellow Perch will be adversely affected in the summer. Further Walleye and Yellow Perch mortality will remain high due to high spring water clarity. The increase in Round Goby will increase growth rates of all predators but also decrease catch rates. We predict that Oneida Lake will remain a great sport fishing lake and at least over the next several decades support a valuable Walleye fishery, but that the fishery will continue to shift towards black bass. When (if) Alewife becomes established sometime in the next 30 years, one of the authors (LGR) believe that Walleye reproduction in the lake will decline dramatically and a Walleye fishery will have to be maintained through stocking fingerlings. These changes in the fish community will continue the current shift in the demographics of anglers using the lake. The lake's fishery has historically been dominated by Walleye, but bass anglers are increasing and large national bass tournaments are now occurring on Oneida Lake.

In contrast to predictions on the future fishery, the predictions of increases in summer blooms of cyanobacteria cannot be seen as positive by any stakeholder group. Mitigating management actions include decreasing nutrient input to the lake through better land use practices in the watershed and improvement to sewage treatment plants to include advanced phosphorus removal systems. Considerable investments in such systems in the Onondaga County Metro Treatment Plant on Onondaga Lake has led to large decreases in phosphorus input into the lake which, coupled with relatively high inputs of nitrates, resulted in high N:P ratios and the disappearance of blue-green blooms from Lake since 2005 (Upstate Freshwater Institute et al. 2014). We are investigating whether internal phosphorus loading from increased anoxia in bottom waters discussed above can or cannot be mitigated by decreases in nutrient loading from the watershed.

Summary

In this concluding chapter, we speculate on the future of Oneida Lake based on our experiences with the lake and recent modeling of the effect of climate change on the hydrodynamics of Oneida Lake. Climate change predictions include increases in summer water temperature, decreases in the duration of ice cover and increased periods of stratification. Increased stratification will promote phosphorus release from anoxic sediments in the summer leading to summer cyanobacteria blooms. Spring water clarity will remain high due to continued filtering from mussels. These changes will promote black bass and Chain Pickerel over Walleye. Climate change will also promote species with currently low winter survival like Alewife, Gizzard Shad, and White Perch. Both Alewife and White Perch will prey on larval Walleye and Yellow Perch thereby decreasing reproduction of these percids, further pushing the lake towards a black bass dominated system. These changes in the fishery may or may not be considered a problem that requires management intervention. The predicted increase in cyanobacteria blooms will be a problem for the future and possible management strategies are expensive as they require improvement to land use and sewage treatment plants. Current work at the Cornell Biological Field Station is investigating the magnitude of phosphorus release from the sediment relative to the loading from the watershed, information that is needed to evaluate the likely effect of any improvement to waste water treatment. Even though our ecological forecasting is based on mechanisms that are supported in the literature, there are uncertainties as new actors arrive to the lake or current rare species become abundant and affect the response of the system. Furthermore, the predictions of increased anoxia depend on the assumption of no change in wind patterns, and predictions of wind patterns are the most uncertain in the climate change models. Here we present our best predictions as of 2015 of the future development of Oneida Lake and expect that surprises will occur. All forecasting, including ecological forecasting, has uncertainties.

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