Atlantic States Marine Fisheries Commission
Habitat Management Series #13
Winter 2016

Habitat Bottlnecks and Fisheries Management

Vision: Sustainably Managing Atlantic Coastal Fisheries

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prepared by the
ASMFC Habitat Committee

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Habitat Bottlenecks and Fisheries Management

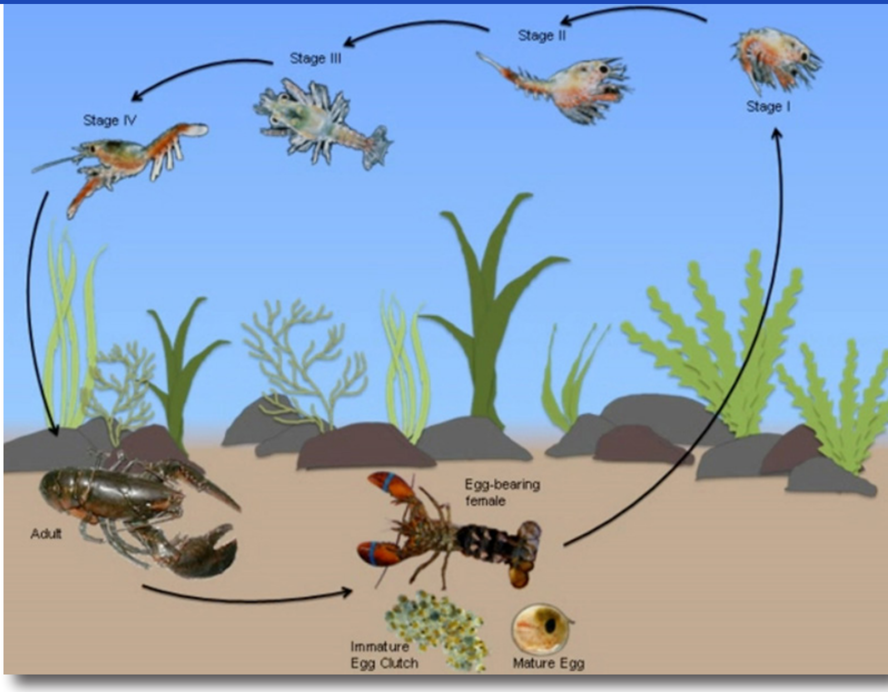

Figure 1. American lobster life cycle.

Introduction

There is little dispute among fishermen, scientists, and fishery managers that the amount, quality, and availability of habitats utilized by diadromous, estuarine, and marine species is a critical determinant of a fish stock's productivity and resilience. However, despite the widespread recognition, conservation of fish habitat remains one of the biggest challenges in fisheries management. There are at least three important reasons for this.

First, patterns (seasonal and temporal) of habitat use by a given species typically vary considerably both within and among life stages. Many species exhibit strong dependence on one or a small number of habitats, but many also show an ability to utilize different habitats at a given life stage in response to prey availability, density, or other factors. Habitat sections of most fishery management plans (FMPs) illustrate the diversity and complexity of habitat use.

Second, quantifying the relationship between habitat metrics (i.e., % cover, patchiness, density of structural features) and stock productivity is difficult for most species[1]. This means that decision-making often cannot be informed by estimates of *X* percent reduction in potential yield of a given species if *Y* acres of habitat are lost or degraded due to a proposed action (e.g., marina development, offshore energy facility, dredging, destructive fishing practice, etc.), or, conversely, that yield will increase due to habitat recovery through protection or restoration. The synergy of multiple impacts which degrade or improve habitat quality very often result in nonlinear or indirect responses in species' productivity.

Third, the range of impacts that affect habitat is broad and fall under the purview of multiple agencies, not solely those responsible for fisheries management. This creates a complex and generally disconnected governance structure that would likely have limited effectiveness even with a stronger and clearer scientific foundation.

In response to these challenges, the Atlantic States Marine Fisheries Commission (ASMFC) Habitat Committee has been working with the concept of *habitat bottlenecks* as a means of focusing both research and management on those areas likely to yield the greatest returns.

[1] An important exception is the generally strong relationship between abundance of anadromous species and accessible river miles.

Definition

The Habitat Committee defines habitat bottlenecks as:

> *A constraint on a species' ability to survive, reproduce, or recruit to the next life stage that results from reductions in available habitat extent and/or capacity and reduces the effectiveness of traditional fisheries management options to control mortality and spawning stock biomass.*

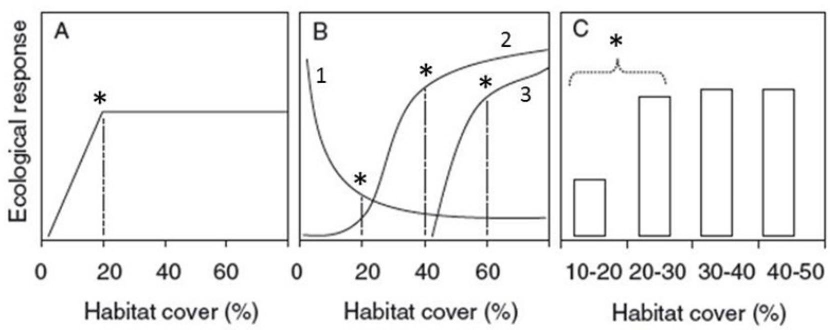

Figure 2. Possible functional relationships between habitat metrics and ecological response variables, such as key demographic rates (growth, mortality, recruitment). Asterisks mark thresholds at which a habitat bottleneck might be created. A and C represent situations in which the response variable is constant, or at least variable within bounds, over a wide range of habitat conditions, but then changes markedly past the threshold. B represents situations where there is an ecological response to habitat across all values, but the rate of change increases or decreases markedly at the threshold. Curve 1 in B represents a response variable that is inversely related to habitat, such as mortality rate. Curve 3 represents a response variable that is strongly tied to habitat, and for which the bottleneck is created when the habitat metric is still seemingly high. An example might be demographic rates during the juvenile stage when individuals are strongly dependent upon nursery habitat for shelter and feeding (modified from Swift and Hannon 2010).

In other words, the concept of a habitat bottleneck is not meant to capture situations wherein the stock's response to changes in habitat conditions is gradual, incremental, or linear. Rather, a habitat bottleneck is a situation in which the response is sharp and pronounced to a degree that it overwhelms the effectiveness of harvest control measures and creates excessive deviation from the constant or bounded conditions assumed by stock assessment models. Figure 2 illustrates potential relationships between habitat metrics and ecological responses in which a threshold exists where the response is sharper and more sudden. Such thresholds are points at which habitat bottlenecks are likely to be created.

This is not to say that more gradual or linear changes are not important. If, for example, a 5% reduction in some key habitat metric causes a 5% reduction in growth rate[2] for a given species, but the stock assessment model does not account for that change, then the actual dynamics will deviate from those predicted by the model and management measures will seem to underperform. However, such a deviation is modest and within the range of expected error and uncertainty, and a response to harvest controls would still likely be observed (assuming other errors and uncertainties are not excessive). A habitat bottleneck is the point at which the deviations from model assumptions are no longer minor and prevent expected responses to management.

[2]Although the definition proposed by the Habitat Committee does not explicitly include growth, among other important attributes (e.g., condition, behavior, etc.), those attributes affect survival, reproduction and recruitment, and therefore are implicit within the definition.

It is important to note that incremental or linear responses to changes in habitat metrics can lead to a habitat bottleneck if the changes are continuous, directional, and not detected scientifically or incorporated into management. For example, a 5% reduction in growth rate due a modest change in habitat might have tolerable effects, but if the reduction grew to 30% through sustained declines in habitat, then the deviation would be excessive even if the change did not look like crossing a threshold (per Figure 2). At that stage, it would also represent a habitat bottleneck. One response might be to take no action on the habitat conditions in the water, and instead adjust the assessment model to better account for the new reality (i.e., lower productivity and recoverability regime). Or, action could be taken to remove the bottleneck and restore the previous productivity regime.

Importantly, habitat bottlenecks can come and go for a given stock in response to changes in habitat condition as well as stock size. Habitat is a key determinant of carrying capacity and adverse impacts on habitat can lower carrying capacity. However, if the stock size is below even the reduced carrying capacity, then a bottleneck will not be evident and the stock should respond to harvest controls. Once the stock approaches the new lower carrying capacity created by changes in habitat conditions, then the bottleneck will become evident as the stock no longer responds as expected under the (incorrectly) assumed conditions.

Categories of Habitat Bottlenecks

Habitat bottlenecks can be categorized as environmental and physical. The distinction differentiates bottlenecks that can be addressed by habitat management measures, such as barriers and direct human activities (physical), from those that cannot be as easily controlled, such as temperature changes (environmental).

Environmental Habitat Bottlenecks
Some species may require specific ranges of environmental conditions such as temperature, pH, salinity, and dissolved oxygen during crucial life stages. Accelerated shifts in these environmental conditions may create habitat bottlenecks that are more challenging, if not impossible, to address with management measures. However, these environmental habitat bottlenecks should be factored into management measures as risks that may compromise a species' ability to rebuild or recruit to the population.

Examples of environmental habitat bottlenecks are temperature shifts for American lobster, oxygen levels for summer and winter flounders, spawning beach availability for horseshoe crab, and access to spawning areas for Atlantic sturgeon (see case studies below). Management measures which accommodate these risks include fishery closures during high temperature months, restrictive size limits to preserve genetically adapting survivors, harvest and quota transfers among jurisdictions, and precautionary trip/bag limits which account for higher mortality rates for vulnerable size classes.

Physical Habitat Bottlenecks
Habitat bottlenecks related to substrate, depth, turbidity, light penetration, water flow, and other physical conditions can be more feasible to address with habitat management measures and activities than the environmental bottlenecks. For example, the New England Fishery Management Council (NEFMC) is proposing to update the winter flounder EFH to better protect spawning grounds from dredging activities in its Draft Omnibus Habitat Amendment 2.

Case Studies

As the Habitat Committee continues to refine the habitat bottleneck concept, we are exploring the utility of new data presented in updates to the Habitat Sections of different FMPs. The following examples illustrate how the concept is being considered and applied in the management of different stocks.

AMERICAN LOBSTER
Addendum XXIII to the American Lobster FMP, which addresses habitat considerations, identifies two observed potential habitat bottlenecks for the species. Neither relate to structural habitat attributes (i.e., benthic features such as vegetation, sessile fauna, or sediment type). Instead, both relate to water quality attributes and the physiological and behavioral responses by individuals within the stock.

Habitat Bottlenecks
The first bottleneck is a temperature threshold effect that was most evident in Long Island Sound at the time of the massive 1999 lobster die-off. Fall water temperatures increased rapidly that year causing thermal stress and mortality, and also caused lobster to aggregate in deeper thermal refuges. These stressed animals were less resistant to several chronic diseases. The result was mortality on the order of 90% or more that year. In subsequent years, continued high temperatures during the fall season caused further physiological stress, overwhelming any expected benefits of fisheries management. Research has demonstrated that lobsters show a distinct and abrupt response to water temperatures above 20°C (Crossin et al. 1998) which field studies have shown can double observed mortality rates (Figure 3), making elevated temperature a true bottleneck for this species.

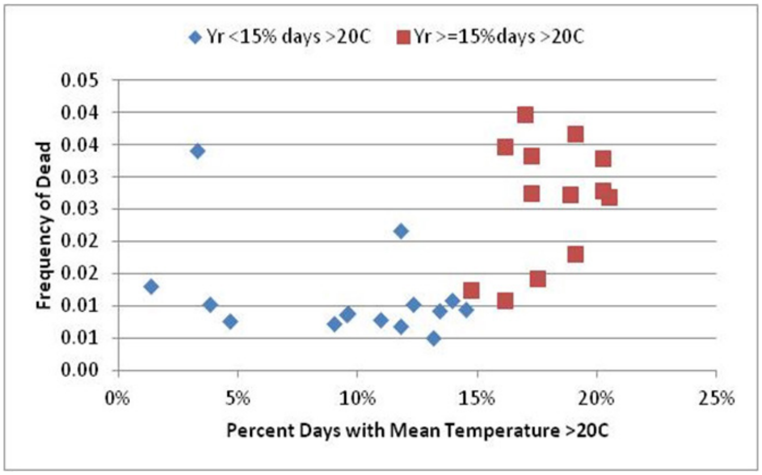

Figure 3. Relationship between the observed annual frequency of dead lobsters in research traps versus the percent of days that year with a mean bottom water temperature above 20°C. (Data provided by Millstone Environmental Laboratory, Dominion Nuclear Resources)

The second bottleneck is also linked to temperature, and involved the reduction and contraction of suitable thermal habitats in several locations off Southern New England (Figure 4). This has caused lobster to be absent from traditional nearshore fishing grounds, reducing availability to the fleet and subsequent yield. There is some evidence that displacement of egg-bearing females into deeper water has resulted in newly hatched planktonic larvae being carried on currents out to open ocean waters where their survival rate is diminished. It is not clear whether and to what extent the stock has experienced a decrease in productivity as a result of these increases in temperature, or whether the change has primarily been one of distribution. Regardless, the effect is similar in that the fishery does not perform as expected.

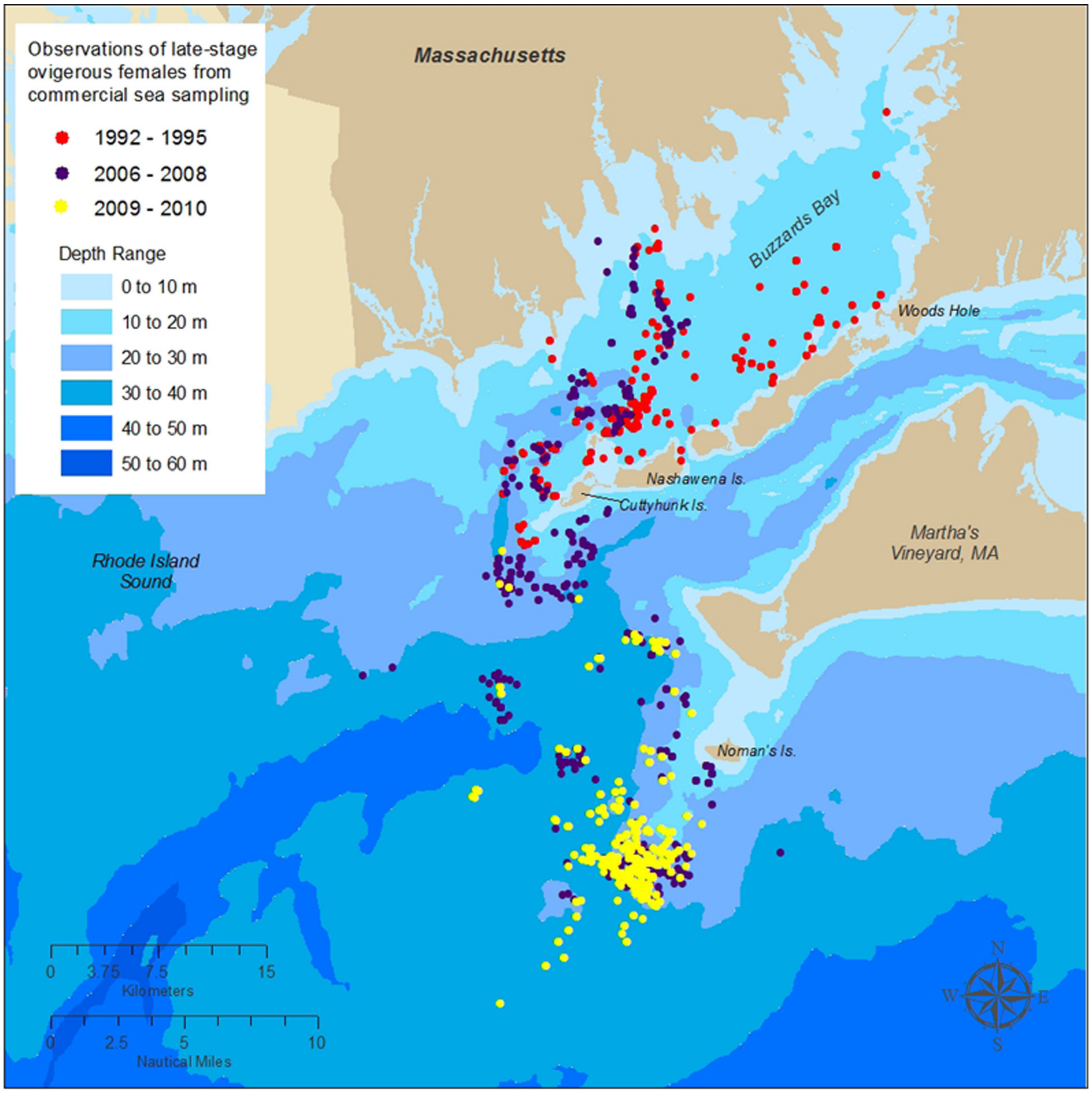

Figure 4. Map of distribution shift in late-stage egg bearing female lobsters in Southern New England that has been related to changes in temperature. From: MA DMF 2011

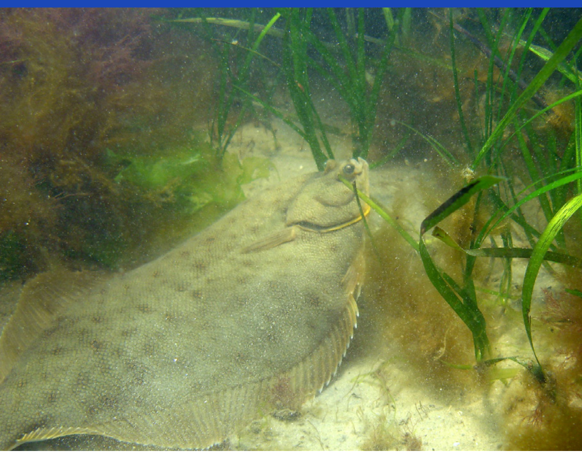
Figure 5. Winter flounder in habitat. Photo credit: Carl LoBue, TNC

SUMMER AND WINTER FLOUNDER

Habitat Requirements

These two specialized flatfish rely on shallow estuaries for their nursery grounds, which contribute substantially to successful recruitment of juveniles to the adult population (Beck et al. 2001). A bottleneck, as defined above, can often develop when these nursery areas experience chronic seasonal hypoxia due to excessive nutrient loading and eutrophication. Laboratory studies of juveniles of these two species (Stierhoff et al. 2006) show that growth of winter flounder at 20°C was reduced by ~50% at both 3.5 and 5.0 mg O_2 l^{-1} (compared to growth at normoxia [7.0 mg O_2 l^{-1}]), and growth was completely halted at 2.0 mg O_2 l^{-1}. Similarly, summer flounder growth was reduced by ~25% at 3.5 mg O_2 l^{-1} and by 50 to 60% at 2.0 mg O_2 l^{-1}. Importantly, there was no evidence of growth acclimation for either species after 7-14 day exposure to hypoxia, and these levels of hypoxia commonly persist in many coastal estuaries. The distinct drop in growth at dissolved oxygen (DO) levels below 3.5 mg O_2 l^{-1} was attributed to reduced feeding rates under hypoxic conditions. These significant reductions in juvenile growth rates, at sizes and ages below those usually modeled for fishery management, can translate into significant reductions in the ultimate production of the entire population (Eby et al. 2005), resulting in overly optimistic model predictions under reduced fishing mortality on the adult stock.


Figure 6. Aggregation of spawning horseshoe crabs. Photo credit: Gregory Breese, USFWS

HORSESHOE CRABS

Habitat Requirements

Horseshoe crabs are evolutionary survivors that have remained relatively unchanged physically for over 350 million years (Figure 6). Of four species worldwide, the one species (*Limulus polyphemus*) in North American waters is the most abundant and ranges on the Atlantic coast from Maine to the Yucatan Peninsula. Adults remain in larger estuaries or migrate to the continental shelf during the winter months, returning inshore in spring to beach areas to spawn. Spawning usually coincides with a high tide during full and new moon phases. Eggs are laid in clusters of a few thousand in buried nest sites along the beach, totaling as many as 90,000 eggs per female per year spread over several spawning events. Such a large number of eggs play an important ecological role in the food web for multiple species of migrating shorebirds specialized in digging them out of the sand. Juvenile crabs hatch from the beach environment and spend their first two years in nearshore nursery grounds. Horseshoe crabs molt at least six times in their first year of life and about 17 times until they become sexually mature at ages 9-12 years. The average life span of adults reaching maturity has been estimated at 20 years.

Habitat Bottlenecks

The most important structural habitat attribute dictating stock status, spawning success, and recruitment is the ready availability of high quality spawning beaches. Despite their primitive physiology, these animals have developed sensory organs that allow them to perceive and chose spawning beaches that promote successful egg development and juvenile survival. These beaches are sloped such that the tidal prism creates an intertidal band with variable inundation and they are thereby protected from strong winds and surf which disrupts the mating process. High quality beaches are composed of a sand/pebble mixture optimal for incubating horseshoe crab eggs in terms of aeration and moisture. From Massachusetts to Delaware, productive spawning beaches are typically coarse-grained and well-drained to maintain adequate oxygen levels; productive southern spawning beaches are typically fine-grained and poorly drained where desiccation is a larger mortality factor (Brockmann 2003).

Figure 7. Predation on horseshoe crabs by predatory birds is common on beaches. Photo credit: Penny Howell, CT Department of Energy and Environmental Protection.

Schaller et al. (2010) concluded that most horseshoe crabs in the Great Bay Estuary in New Hampshire tended to spawn on beaches nearer to where they overwintered. Landi et al. (2014) also found that the probability of a beach segment in Connecticut falling into a higher use category increased with increasing slope, decreasing wave exposure, and decreasing distance from offshore congregations of overwintering adults. Therefore the distribution of high quality spawning beaches, which are exposed to only minimal human disturbance, also presents a bottleneck to reproductive success for this species. Disruption to beaches during the spawning season should be minimized by both reducing direct (e.g. harassment of horseshoe crabs, eggs, or predatory birds, Figure 7) and indirect (e.g. bulkheads and riprap) human impacts. In addition to tightly managing horseshoe crab removals, an effective management strategy should recognize and accommodate linkages among offshore overwintering grounds, high quality spawning beaches, and juvenile nursery areas, maintaining priority beach habitat long term. Seasonal area closures designed with these linkages in mind would optimize horseshoe crab reproduction and recruitment, while also promoting their contribution to the regional food web. Restrictions on development and regulations on shoreline hardening, as well as enforcement of existing and future regulations are recommended. This includes the appropriate use of living shoreline designs to maintain beach slope and energy characteristics in the face of sea level rise.

ATLANTIC STURGEON

Atlantic sturgeon is a highly migratory anadromous fish, and each estuary analyzed hosts one or more genetically distinct populations (Grunwald et al., 2007; Balazik and Musick 2015). Historically, Atlantic sturgeon were documented in 38 rivers ranging from Labrador to the St. Johns River in Florida. Thirty-five of these historical rivers currently have Atlantic sturgeon present, but only 21 (possibly only as few as 19) have one or more extant breeding populations (ASSRT, 2007, Table 1, p. 140; Hager et al. 2014; Balazik and Musick 2015).

Physical Bottlenecks

DAMS - Spawning and recruitment appears to be most successful in rivers without dams blocking access to historical spawning habitat (hard surfaces such as cobble). These include the Hudson (NY), James (VA), and Altamaha (GA) Rivers. The Cape Fear (NC), Santee-Cooper (SC), and St. Johns (FL) river systems have lost greater than 62% of the habitat historically used for spawning and development; only 42% of the historical habitat is available in the Merrimack River (MA, ASSRT, 2007). Barriers to spawning areas can cause females to resorb eggs and not spawn. Fish passage measures beneficial (i.e. safe, timely, and effective) to Atlantic sturgeon have had limited success but alternate designs are being developed (Schilt 2007; Kynard et al. 2008; Katopodis and Williams 2012). In addition to being a physical barrier, dams can alter or degrade sturgeon habitat downstream by reducing water quality and availability of spawning habitat through temperature, flow, or oxygen content changes. Water flows (both seasonal flow timing and natural rate of flow delivery affect habitat suitability), water temperatures, and concentrations of DO are all affected by peaking operations from hydroelectric facilities.

DREDGING - Removal and displacement of sediment modifies the quality and availability of Atlantic sturgeon habitat, mainly through sedimentation. It can alter overall water quality (salinity and dissolved oxygen) greatly reducing the value of foraging and nursery habitat. Dredging operations have also been documented capturing 14 Atlantic sturgeon from 1990-2005 (ASSRT, 2007).

Environmental Bottlenecks

Secor and Gunderson (1998) noted a correlation between low abundance of Atlantic sturgeon and decreasing water quality caused by increased nutrient loading and increased spatial and temporal frequency of hypoxic conditions. Frequent occurrences of low DO concentrations in combination with high summer water temperatures are a particular concern. A bioenergetics and survival model for Chesapeake Bay demonstrated that a combination of low DO concentration, water temperature, and salinity restricts available Atlantic Sturgeon habitat to 0-32.5% of the Bay's modeled surface area during the summer (Niklitschek and Secor, 2005). Sturgeon are more sensitive to low DO concentrations (<5 mg l^{-1}) than other fish species (Niklitschek and Secor, 2009a, 2009b) and experience sublethal to lethal effects as DO concentration drops and temperatures rise. Summer mortality has been observed at <3.3 mg l^{-1} and at 26°C.

Final Thoughts

Over the course of writing this paper, the Habitat Committee discussed the role that humans play in the marine environment, both indirectly and directly. Arguably, humans have had some influence, either directly (e.g. shoreline hardening) or indirectly (e.g. through CO_2 emissions, thus increasing water temperature), on each habitat bottleneck addressed above. Because of the complex interactions among humans, habitat, and other environmental factors (both biotic and abiotic), it was at times difficult to focus on the effects of habitat bottlenecks without acknowledging other potential influences on spawning stock biomass. We ask that the reader please keep the intended scope of this paper in mind, as it is not a comprehensive examination of all of the variables that can impact fisheries, whether natural or anthropogenic.

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