BAY ANCHOVY
Anchoa mitchilli

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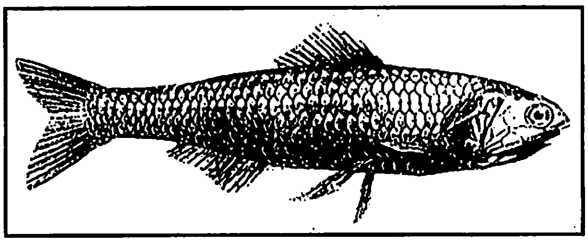

The bay anchovy, a small, schooling species, is the most abundant fish in Chesapeake Bay. It is a major consumer of plankton and is itself a major food of predatory fish, making it a key species in the Bay's food web. The bay anchovy occurs throughout the Bay and is widely tolerant of salinity and temperature. It lives to three years of age, seldom grows longer than 90 mm, and spawns in late spring and summer when low dissolved oxygen (DO) may limit the distribution of all life stages. Oxygen levels below 3.0 mgL^{-1} can be lethal to eggs and larvae and DO below 2.0 mgL^{-1} is critical. Specific habitat features, structure, and shoreline development are not of particular concern for bay anchovy, but hydrographic features that affect water quality could limit its distribution and abundance. Surprisingly little is known about toxicant effects on bay anchovy. Bay anchovy losses from being entrained and impinged in power plant cooling systems may affect its abundance as well as that of fishes that consume it.

Bay anchovy populations in the Chesapeake Bay fluctuate annually, but no long-term declines have occurred. Deteriorating water quality in the future could affect its reproductive potential. Summer hypoxia already potentially limits its distribution and productivity in the Maryland portion of Chesapeake Bay. A better knowledge of toxicant effects on all life stages and better definition of the bay anchovy's key role in food webs will be important to define water quality criteria that may be critical.

INTRODUCTION

The bay anchovy is the most abundant fish in the Chesapeake Bay. This small, unexploited species is widely distributed along the Atlantic coast of the United States where it plays a key role in estuarine and coastal food webs. It is a schooling species that is a major consumer of plankton and is itself a major prey of large predatory fish, including bluefish, striped bass, and weakfish. Bay anchovy abundance has fluctuated significantly in Chesapeake Bay in recent years, but there is no evidence of a declining trend.

Water quality criteria may be more important than physical structure or habitat features in determining the bay anchovy's well-being, but surprisingly little is known about its vulnerability to anthropogenic inputs of toxicants. Low DO during summer, which limits habitat availability to all life stages, is potentially an important factor controlling population production of bay anchovy. The "top-down" influence of bay anchovy grazing on plankton and its effect on water quality also are of interest to ecologists concerned with food webs, community structure, and water quality restoration in the Chesapeake Bay.

BACKGROUND

Geographic Range

Two *Anchoa* species occur in the Chesapeake Bay and the mid-Atlantic region: *A. mitchilli* and *A. hepsetus* (striped anchovy). Adults of these species can be differentiated based upon their morphology and fin ray counts.[36] Bay anchovies occur along the Atlantic Coast from Maine to the Yucatan Peninsula, including the Florida Keys.[5,6,18] They may have the largest biomass of any estuarine fish found along the U.S. South Atlantic and Gulf Coasts.[32] Information on bay anchovy life history, environmental requirements, distribution and abundance has been summarized in species profiles.[69,72,78]

Bay anchovy is the most abundant fish in the Chesapeake Bay[29,36] and occurs throughout its waters[41] (Map Appendix). Adult bay anchovy migrate during winter to deeper waters in the Chesapeake Bay[36,86] and to the inner continental shelf in other regions, returning to estuaries in the spring.[13,33,34,98] Larvae and small juveniles are distributed throughout Chesapeake Bay; some migrate or are transported into low salinity subestuaries, remaining there until fall before dispersing to over-wintering areas.[24,63,87]

Over its geographic range, bay anchovy is a nearshore, coastal, and estuarine species. It seldom occurs in waters deeper than 25 m,[8] but has been collected in 27-36 m depths.[34] Bay anchovy inhabits both clear and turbid waters and has been collected over all types of substrates, including muddy coves, grassy areas, surf zones, oyster bars, sandy beaches, and sand and silt bottoms.[5,36,56,80,98]

Bay anchovy is pelagic in all life stages. The reported vertical and horizontal distributions of each life stage are variable and not readily predictable. Dalton[17] reported that mean egg densities were significantly higher in near-bottom samples than in surface samples in the mid-Chesapeake Bay. However, Houde[46] found both eggs and larvae to be primarily above the pycnocline on two widely separated transects in the Bay. Larval and juvenile bay anchovies in the upper Chesapeake Bay were most abundant near the surface [upper 10 feet (3 m)] from May to October but apparently moved to deeper waters as winter approached.[24] Setzler *et al.*[87] found higher larval densities at shoal stations in the Patuxent River than in channel stations, although the reverse was true for eggs. The depth distributions of larvae in the Patuxent River were complex, varying in relation to larval size, time of day, and river area where they were found.[63]

Juvenile bay anchovy were collected as much as 40 miles (64 km) above brackish water in Virginia tributaries.[67] Kaufman *et al.*[53] found juveniles were most abundant in near-surface waters in the upper Chesapeake Bay and Kernehan *et al.*[55] reported that juveniles in the Chesapeake and Delaware Canal were most abundant near surface during the day but in mid- to bottom waters at night. Adult bay anchovies were collected throughout the water column in the Delaware River estuary.[78] Surface schools of bay anchovy are often seen in the upper Chesapeake Bay[53] and in the mid-Chesapeake Bay,[49] particularly in frontal areas at the mouths of rivers.

Population Status and Trends

Trawling, seining and ichthyoplankton surveys in the Chesapeake Bay all indicate that bay anchovy populations fluctuate widely from year-to-year. No long-term trend in abundance is apparent.

Peak reported mean densities of anchovy eggs are high,[17,46,74] ranging from 4.02 m^{-3} to 232.00 m^{-3} in Chesapeake Bay (Table 1). Mean larval densities[17,46,74] ranged from 0.9 to 76.10 m^{-3} in the Bay (Table 1).

Indices of adult bay anchovy abundance varied more than 100-fold in summer beach-seine surveys from 1958-1989 in low salinity tributaries of Chesapeake Bay.[66] The 32-year mean abundance index was 25.7 bay anchovies per seine haul. The highest index value was 105.9 in 1967 and the lowest was 0.75 in 1958.[73] The 1986 index of 44.3 was nearly four times higher than the 1987 value of 12.1.

Year-round bottom trawl catches in the mid-Chesapeake Bay from 1969-1981[41] indicated that bay anchovy abundance varied seasonally and annually. There were usually two seasonal abundance peaks, one in spring (May) and another in fall (September-November), with the fall peak more than two times higher than the spring peak. Lowest catches occurred in winter. Mean annual catches per tow ranged from a low of 58.5 in 1976 to a high of 973.9 in 1980 (Table 2). The 13-year mean was 708.0 anchovies per tow.

Abundance trends in the mid-Bay trawl surveys[41] were similar to trends in trawl surveys in the lower Bay's York and Rappahannock Rivers[103] in six of the 12 years of concurrent trawling. Abundances in both surveys were low in 1971, 1972, and 1976 and were generally high in 1977, 1980, and 1981. Mean trawl catches in the York and Rappahannock Rivers ranged from 0 in 1966 to 400 in 1980 (Table 2). Trawl catch-per-unit-effort (CPUE) of bay anchovy in mid-Chesapeake Bay surveys during 1986 and 1987 was almost six times higher in 1986[73] (Table 2). Peak abundance occurred in September of each year. Bay anchovy dominated the total fish catch (65%) in numbers during a 1988 trawl survey in the mainstem of Chesapeake Bay's Virginia waters.[12] The CPUE ranged from 19.1 in February to 1,888.7 in December. The mean 1988 CPUE was 584.3 anchovies per tow (Table 2).

LIFE HISTORY

All life stages of bay anchovy are found in the Chesapeake Bay.[36] The high abundances of eggs and larvae indicate that the Bay is a major spawning and nursery area.[17,24,74]

Spawning

Spawning by bay anchovy in the Chesapeake Bay is widespread (Map Appendix) and occurs from May to September, with peak spawning in July.[17,24,64,74,104] The protracted spawning season may extend throughout the year in southern parts of its range,[50] but is shorter at higher latitudes. Bay anchovy is a batch (i.e., serial) spawner.

Individual females in the Chesapeake Bay spawn at least 50 times each season, producing a mean of 1,129 ova per batch.[104] Bay anchovies spawn in the evening between 1800 and 2400 hours.[26,35,64,104] Batch fecundity averages 643-740 eggs per gram of female.[64,104] Bay anchovies spawn where water depth is less than 20 m[81] in salinities from 0-32 ppt.[78] Peak spawning in Chesapeake Bay apparently occurs at 13-15 ppt[24] and at average surface water temperatures from 26.3-27.8°C.[49,54] In the Delaware estuary, peak spawning occurred at 22-27°C.[99]

Age I females produced from 92 to > 99% of the eggs spawned in July of 1986 and 1987 in mid-Chesapeake Bay. Thus, a reproductive failure in one year could drastically reduce future numbers of Age I females and have a major impact on egg production.[104]

Eggs

The approximately 1 mm fertilized eggs are pelagic, slightly ellipsoid with segmented yolk-mass and no oil globules.[52,99] Time to hatch was reported as 24 h at 27.2-27.8°C,[57] but this may have been an overestimate because egg stage duration was 24 h at 25°C[44] and was approximately 18 h at 28-29°C.[47] Eggs have been collected in most areas of the Bay and its tributaries (Map Appendix). Egg mortality rates are believed to be high. In Biscayne Bay, Florida, egg mortality averaged 86%.[60]

Larvae

The larval stage may be the most sensitive life stage of bay anchovy in the Chesapeake Bay. Larvae are 1.8-2.0 mm long at hatch.[57] The yolk sac is absorbed in 27 h at 32°C and in 41 h at 24°C.[43] Feeding at 25-28°C was initiated at 3.4 mm length and 2-3 days posthatch.[43] Laboratory-reared larvae that were offered a range of food concentrations grew from 0.37-0.59 mm d^{-1}.[51]

Bay anchovy larvae enclosed in 3.2 m^3 *in situ* mesocosms in the Patuxent River grew 0.39-0.63 mm d^{-1}.[16] Larvae in the Patuxent River were reported to grow at > 0.70 mm d^{-1} in 1982,[29] based on otolith increment counts. Otolith-aged larvae from Biscayne Bay grew 0.43 to 0.56 mm d^{-1} [60] while those in the Newport River, North Carolina, reportedly grew at 0.25-0.31 mm d^{-1}.[28] Larval mortality rates are high. A 25% per day mortality rate was estimated recently in Chesapeake Bay,[46] compared to an estimated rate of 26-36% per day in Biscayne Bay, Florida.[60]

Juveniles

Juvenile bay anchovies are approximately 25-40 mm long. In mid-Chesapeake Bay their growth rates ranged from 0.20-0.33 mm d^{-1} in 1986 and 1987.[71,73] The larval and juvenile stages may be completed in as little as 2.5 months and some Chesapeake Bay young-of-the-year may mature by late summer,[64] although most apparently overwinter before maturing the following year.[104]

Adults

Bay anchovies may live to be slightly more than three years old, although few otolith-aged individuals had survived to that age.[73,78] Adults may attain a maximum length of 110 mm.[34] Mean lengths of adults in mid-Chesapeake Bay[73] were 55.0 mm fork length (FL) at age I, 70.7 mm FL at age II and 83.1 mm FL at age III. Average annual mortality rates are high, ranging from 89-95% per year.[73] Females are generally more abundant than males in trawl collections.[73,78,94,98]

ECOLOGICAL ROLE

The bay anchovy plays a key role in the Chesapeake Bay food web. It is a major consumer of zooplankton and a dominant prey item in diets of commercially and recreationally important predatory fish including striped bass, weakfish, bluefish, and summer flounder.[2,10,39,40,68,85]

The diet of juvenile and adult bay anchovies consists primarily of zooplankton, which are eaten selectively as individual particles. Copepods are the dominant prey.[78,94,97] Large bay anchovy add macrozooplankton to the diet, such as mysids, larval fish, crab larvae, and other invertebrates, and including some benthic organisms (e.g., polychaetes and molluscs). Small particulates (e.g., algae and detritus) may be found in stomachs of all anchovy length classes.[1,3,9,19,20,33,40,79,80,89,90,97,101] The dominance of copepods in the diet may be replaced when other potential foods are abundant.[22] Feeding may occur throughout the day, but during summer months in Chesapeake Bay it is most intense from dawn to mid-morning.[40,97] Daily ration was estimated to be 16.2% of body weight.[97] Food consumption and other energetics parameters were temperature-dependent in the 19-27°C range, with highest consumption and growth at 27°C.[97]

The bay anchovy is preyed upon by seabirds, including the common tern,[84] and might be an important food item for waterfowl and other animals.[24] Bay anchovy provides more than half of the total energy intake of predatory fish in Chesapeake Bay, contributing 70, 90 and 60% to their diets in summer, fall and spring, respectively.[2]

Potential competitors of bay anchovy are other plankton-eating fishes, including menhaden and silversides. The bay anchovy diet was demonstrated to overlap with that of blueback herring in the James River, Virginia.[7] Ctenophores (comb jellies) and other jellyfish (e.g., sea nettles) are major consumers of zooplankton in Chesapeake Bay[2] and may compete for it with the bay anchovy.

The reported first food of larval bay anchovies is microzooplankton, including copepod nauplii, rotifers, and tintinnids.[21,50] Older larvae fed upon larger copepodites and adult copepods.[21] Larvae from Biscayne Bay, Florida ate primarily copepods (75.4%) but included tintinnids, rotifers, and bivalve larvae in their diet.[50]

Larval bay anchovies require food within 2.5 days after hatching at 26°C.[43] High larval growth rates and survival rates were obtained at microzooplankton prey levels near ambient and as much as ten-fold below ambient in *in situ* enclosure experiments in the Patuxent River,[16] indicating that food levels in Chesapeake Bay subestuaries generally are adequate for larval production. Based upon laboratory studies, Houde[44,45] had suggested that 100 microzooplankton per liter was a critical food level for bay anchovy larval survival, but the Patuxent River enclosure experiments indicate that concentrations as low as 50 L^{-1} may suffice.[16]

Bay anchovy eggs and larvae, being the dominant ichthyoplankton in the Chesapeake Bay,[17,24,74] are believed to interact significantly with many predators and prey. Gelatinous zooplankton, including sea nettles, ctenophores, and other medusae, are predators on eggs and larvae[15,70] and also may compete with larvae for zooplankton food. Adult bay anchovy may be cannibalistic; they have consumed bay anchovy eggs in experiments.[15] The importance of cannibalism is unevaluated but is a potentially important mechanism of population regulation. The sea nettle, which reaches peak abundance in summer, may be the most effective predator on bay anchovy eggs and larvae in Chesapeake Bay.

HABITAT REQUIREMENTS

Water Quality

Dissolved Oxygen

Dissolved oxygen concentrations below 3.0 mgL^{-1} probably limit the viability and productivity of bay anchovy in the Chesapeake Bay. Laboratory experiments on bay anchovy eggs and yolk-sac larvae indicated that LC_{50} was 2.8 mgO_2L^{-1} for eggs and 1.6 mgL^{-1} for yolk-sac larvae.[11] Egg hatchability declined significantly below 3.0 mgL^{-1}. Survival of newly-hatched larvae declined below 2.5 mgL^{-1}. Many 12-24 h posthatch larvae survived at concentrations between 2.0 and 2.5 mgL^{-1} and some survived when DO was between 1.0 and 2.0 mgL^{-1}. The long-term consequences of low oxygen on larval survival and growth are unevaluated.

Large volumes of the Chesapeake Bay in summer have median DO below 3.0 mgL^{-1} and 2.0 mgL^{-1} (Map Appendix), thus limiting availability of bay anchovy habitat, especially in the Maryland portion of the Bay. Concentrations below 3.0 mgL^{-1} mostly are confined to depths > 8-10 m (i.e., subpycnocline). In one study, bay anchovy eggs were reported to be abundant at subpycnocline depths,[17] but recent data indicate that few eggs or larvae are found there when DO is low.[47]

Salinity

All life stages of bay anchovy occur over a wide salinity range in the Chesapeake Bay (Map Appendix; Table 3) and in other ecosystems. Eggs in Chesapeake Bay, Delaware Bay, and the Potomac River occurred at salinities from < 1 to 32 ppt.[24,78,86] Egg viability may be low at salinities below 8 ppt.[99] Reported suitable salinities for eggs were 4-9 ppt,[61] 1-22 ppt,[24] and > 20 ppt.[78] Highest egg densities were observed at salinities from 13-15 ppt in the upper Chesapeake Bay[24] and at 17-23 ppt in the polyhaline lower Bay.[74] In Delaware Bay higher percentages of live eggs were found in higher salinity waters (20-30 ppt) than in lower salinity waters (< 15 ppt).[99] Larval bay anchovies occurred in Chesapeake Bay at salinities from 0.0-31.9 ppt[17,24,74] and were reported at salinities as high as 36.5 ppt in Biscayne Bay, Florida.[50]

Juvenile and adult bay anchovy throughout their range are euryhaline and have been collected in salinities from 0-80 ppt.[24,67,78,92] Salinity apparently has minor influence on the distribution of bay anchovy.[31,56,79,93] The preferred salinity range apparently is 9-30 ppt in Chesapeake Bay (Table 3), although adults occur throughout the salinity gradient (Map Appendix) which ranges from 0 ppt[24] to 31.9 ppt.[74]

Turbidity and Suspended Sediments

Bay anchovies often live in turbid waters and may be attracted to high turbidities.[62] No information specific to Chesapeake Bay is available, but significant mortality of adults occurred in static bioassays of fuller's earth suspensions of 2.31, 4.71 and 9.60 gL^{-1} (10, 50 and 90% mortalities, respectively) after 24 h exposure.[91] Suspended sediment concentrations > 250 mgL^{-1} caused a reduction in food ingestion by copepods, a primary food of bay anchovy.[91]

Temperature

Preferred temperatures for bay anchovy eggs are in the broad range of 13-30°C (Table 4). Eggs have been collected in Chesapeake Bay waters from 9.0-31.0°C,[24] indicating a broad tolerance to temperature (Table 4). However, laboratory studies on naturally fertilized eggs indicated that successful incubation temperatures were 17-25°C for eggs collected in the Delaware River.[78] Seventy-six to 100% of eggs acclimated to 27°C hatched following induced temperature changes of 1.5-7.0°C for 0.5-5.0 h duration.[78]

Preferred temperature ranges for bay anchovy larvae are 15-30°C (Table 4). Larvae tolerated temperatures as high as 35°C in 1-5 minute exposures after acclimation at 17-25°C.[78] Juveniles in Chesapeake Bay can tolerate temperatures from 0-31oC24 but may prefer 10.0 to 30.0oC (Table 4).

Adults tolerate a wide range of temperatures (Table 4) in all seasons in Chesapeake Bay where monthly mean surface water temperatures range from 3.4°C in January to 26.3°C in August.[54] They occur at temperatures from 2.2-27.1°C in the Hudson River Estuary[25] and 16-34°C in the Everglades, Florida.[83] Preferred temperatures of adults in Texas estuaries were 8.1-32.2°C,[100] with a possible upper lethal limit of 40°C.[14]

Habitat
Structure, except for that associated with water column hydrography, is not believed to be important for the pelagic bay anchovy. In Chesapeake Bay, the anoxic or hypoxic (< 3.0 mgO_2L^{-1}) waters below the pycnocline during summer (Map Appendix) may limit habitat available to all life stages and may force bay anchovies to be distributed nearer to the surface than otherwise.

Substrate
Bay anchovy has been collected over many substrates, including sand, mud, sea grass, oyster shell, and the hard bottoms of beaches in surf zones.[5,36,56,80,98] There is no indication that it prefers any particular substrate.

Vegetation
Seagrass beds in Chesapeake Bay were not important spawning sites for bay anchovy or other fishes that produce pelagic eggs.[75] There also is no indication that they are important nursery areas for bay anchovy larvae.

Depth
Bay anchovy has been collected from waters as deep as 27-36 m,[34] although it generally occurs in shallower depths. Eggs have been collected throughout the water column (surface to > 20 m depth) in the Chesapeake Bay.[17,46] Unpublished information[46] indicated that egg densities were 6.5 times higher above the pycnocline than below it, and that larval densities were 8.4 times higher above the pycnocline. Small larvae tended to remain farther below the surface in the Patuxent River mouth than did > 11 mm larvae, which showed no depth preference.[63] Upstream in the Patuxent, the larval depth distribution and factors influencing it became more complex.[63]

Juvenile and adult bay anchovy may occur throughout the water column in Chesapeake Bay[48] and Delaware Bay.[78] There is some published evidence that schools tend to be located nearer to surface than to bottom,[53,55] but recent hydroacoustic surveys[48] indicate that changes in depth distribution occur, both seasonally and diurnally, that are not well understood.

Weather
Seasonal changes in water temperatures may cause offshore migrations during winter by bay anchovy in the temperate parts of its range.[98] It is not certain whether winter temperatures induce offshore migration of some Chesapeake Bay anchovies. Some bay anchovies were collected by otter trawl during all months in a 13-year program in the mid-Chesapeake Bay.[41] Trawling surveys after tropical storm Agnes in June, 1972, indicated that adult bay anchovy abundance was not affected in the middle or southern portions of the Chesapeake Bay.[82,38] Large numbers of bay anchovy larvae may have been swept out of the James and Rappahannock Rivers into the Bay during the flood following the storm.[37] Dalton[17] found two peaks in egg abundance during 1972, one before and one after tropical storm Agnes. Egg abundances were low 30 days after the storm and the 1972 annual mean larval density was 18 times lower than the mean density for the four years of 1972, 1974, 1976, and 1977.

SPECIAL PROBLEMS

Contaminants
Despite the bay anchovy's abundance, there is surprisingly little information on toxicants. Contaminant problems from use of chlorine in power plant[78] and sewage plant discharges may be problematic. Bay anchovy was the dominant fish within areas of Galveston Bay that reportedly received highest pollutant loads,[3] suggesting to the authors that the bay anchovy dominance might be an indicator of pollution stress.[3,69] The increased turbidities associated with kraft pulp mill effluent, which contained toxins, may have attracted bay anchovies, despite the pollutant level.[62]

Parasitism and Diseases
Unidentified parasitic trematodes were found in 19.3% of Chesapeake Bay adult bay anchovy stomachs in 1986 and 1987.[97] Parasitic copepods are frequently observed on bay anchovy, especially in summer and fall.[58,59] A parasitic brachyuran (crab) also has been observed attached to larval and juvenile bay anchovies.[78] Fin-rot disease on bay anchovies in New York Bight was attributed to dense bacterial populations and environmental stress from domestic and industrial pollution in 1967-1971.[65]

Power Plant Entrainment and Impingement
The abundance, small size, and widespread occurrence of bay anchovy make all life stages vulnerable to entrainment in power plant cooling waters or impingement on screens designed to prevent entrainment of organisms.[42,76,78,95] On-site studies in the Delaware River estuary[78] indicated that most anchovy eggs and larvae were entrained from May through October. Juveniles and adults were entrained in all months except February and December. Numbers entrained were sometimes high.

Most mortality in both intake and discharge samples at a Delaware River power plant occurred in the first six hours following entrainment although some mortality continued for at least 24 h[78] (Table 5). In laboratory studies that simulated the mechanical stress of entrainment, mortality was significant for all life stages except prolarvae.

Mortality of early life stages was variable, but tended to increase as the temperature differential in simulated cooling waters increased.[78]

Simulation models were used to predict bay anchovy entrainment losses at a power plant on the Patuxent River near Chalk Point.[76] A reduction in juvenile survival of up to 76% was possible, primarily from losses during the postlarval stage (10-35 mm), because that stage was concentrated where entrainment probability was highest. The authors[76] believed that the probable range of loss due to entrainment was 24-76%.

Another simulation model[95] for the same power plant predicted that bay anchovy standing stock might decline by 46% and that predatory fish, such as striped bass, bluefish, and weakfish could experience standing stock losses of > 25% if bay anchovy and silversides were the preferred prey and if their entrainment losses were ≥ 70%. If, as seems likely, the entrainment losses were lower, perhaps only 30%, then bay anchovy standing stock would decline by 21% and piscivorous fish standing stock by 10-15%. If anchovy and silversides were not the major component of predator diets, then losses of predator production would be small.

Bay anchovy was the most common species impinged at a nuclear power plant in mid-Chesapeake Bay from 1975-1983.[42] Most impingement occurred from April-June and in November; the least occurred in February and March. Bay anchovy had intermediate rates of survival (45-90%) compared to other impinged species. The estimated number of anchovies impinged annually ranged from 5,219 (in 1982) to 1.1×10^6 (in 1981). Age I fish were the dominant group impinged. Horwitz[42] noted that the consequences of impingement mortality depend upon its magnitude relative to other sources of mortality; he concluded that impingement mortality at the Chesapeake Bay nuclear power plant probably was small relative to total mortality.

RECOMMENDATIONS

Although there is no evidence of population decline or instability in the bay anchovy population in the Chesapeake Bay, there are concerns. Two recommendations may improve habitat conditions and insure future well-being of the bay anchovy population.

1) Reduce the volume of water that becomes anoxic or hypoxic (< 3.0 mgO_2L^{-1}) during summer and thereby expand the productive habitat of all life stages of bay anchovy. Also, reduce the frequency of transient, low DO events (< 2.0 mgL^{-1}) through appropriate Baywide nutrient reduction strategies.

2) Carefully consider the siting of proposed power plants that may entrain and impinge all life stages of bay anchovy, potentially affecting not only anchovy productivity but also that of large, predator fishes that depend upon bay anchovy as food.

Some research recommendations that will enhance our knowledge of this key species and its sensitivity to habitat change in Chesapeake Bay include:

1) Determine the sensitivity of all life stages to potential toxicants.

2) Estimate the biomass and production of bay anchovy, and their annual variability.

3) Estimate the amounts and kinds of plankton consumed by the bay anchovy population on an annual basis to determine its potential "top-down" control on plankton production, community structure, and water quality.

4) Determine the fraction of the standing stock of bay anchovy consumed annually by predator fish to quantify its key role in the Bay's food web.

CONCLUSIONS

The bay anchovy is abundant and ubiquitous in the Chesapeake Bay where it plays a key role in the food webs of the plankton and pelagic fish communities. The bay anchovy population is in no immediate danger of decline from present habitat conditions or water quality, but it is important to be alert for potentially deleterious effects of toxicants, power plant operations, and nutrient pollution causing summer hypoxia. The population dynamics and trophic relationships of bay anchovy in Chesapeake Bay are just beginning to be understood. A better knowledge of bay anchovy's role in the Bay trophic structure will be important for long-term management of Chesapeake Bay water quality and fish resources.

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Table 1. Summary of mean bay anchovy egg and larval densities. Collections were made with various types of sampling gear. Life stage: E = eggs; L = larvae; A = adults.

Location	Time period	Life stage	Peak density #/100 m^3	Percent of total catch	Reference
Barnegat Bay, N.J.	1975-1981	E	13250[a]	98	98
		L	1120[a]	56	
		A		52	
Biscayne Bay, Fl.	1976-1977	E	10150[a]	55.8	50
		L	246[a]	20.1	
mid-Chesapeake Bay	1972-1977	E	3500[b]	99	17
		L	200[b]		
lower Chesapeake Bay	1971-1976	E	14000[a]	96	74
		L	2403[a]	88	
mid-lower Chesapeake Bay	1987	E	23200[c]		46
		L	7610[c]		
upper Chesapeake Bay	1963-1967	E	43000[d]		24
Patuxent River	1960-1971	L	16400[d]		25
	3/78/8/78	E	402[a]		87
		L	38[a]		
Potomac River	1974-1976	L	90[d]		86
Hudson River	4/72-8/72	E		99.8	25
		L	23600[d]	70	

[a] monthly mean
[b] 1974 average
[c] cruise and station mean
[d] single collection

Table 2. Summary of bay anchovy abundance in Chesapeake Bay. Indices are counts of fish per unit effort.

Location	Years	Gear	Unit effort	Range of abundance index	Reference
low-salinity tributaries	1958-1989	beach seine	haul	0.75(1958)-105.9(1967)[a]	73[c]
mid-Bay	1969-1981	7.6 m balloon trawl	30 min. tow	58.5(1976)-973.9(1980)[a]	42
York and Rappahannock Rivers	1955-1982	30 ft. semi-balloon trawl	5 min. tow	0(1966)-400(1980)[a]	103
mid-Bay	1986-1987	4.9 m semi-balloon trawl	10 min. tow	54(1987)-354(1986)[a]	73
Virginia mainstem Bay	1/88-12/88	30 ft semi-balloon trawl	5 min. tow	19.1(Feb.)-1888.7(Dec.)[b]	12

[a] mean annual abundance.
[b] annual mean = 584.3; bay anchovy were 65% of the total number of fish caught.
[c] MDNR data 1958-1989 cited in 73.

Table 3. Salinity ranges for bay anchovy occurrence.

Life stage	Minimum salinity ppt	Maximum salinity ppt	Preferred or optimum range (ppt)	Location	Reference
EGGS			4.0-20.0	overall suitable range	
	1.0	22.0	13.0-15.0	upper Chesapeake Bay	24
			4.0-9.0	Potomac River	61
	0.0	32.0	> 20.0	Delaware River estuary	78
	< 1.0		6.0-10.0	Potomac River	86
	> 8.0		20.0-30.0	Delaware River estuary	99
	6.4	31.9	17.0-23.0	lower Chesapeake Bay	74
LARVAE			0.0-15.0	overall suitable range	
	0.0		3.0-7.0	upper Chesapeake Bay	24
			4.2-6.0	Hudson River	25
	6.4	31.9		lower Chesapeake Bay	74
			0.0-> 5.0	Potomac River	61
	0.0	31.0		Delaware River estuary	99
	0.0	49.0		Alazan Bay, Texas	23
JUVENILES			9.0-30.0	overall suitable range	
	≤ 0.5[a]			Delaware River estuary	77
			3.0-7.0	upper Chesapeake Bay	24
	> 2.3		20.8-37.6	Florida Gulf coast	56
ADULTS			9.0-30.0	overall suitable range	
			13.0-15.0[b]	upper Chesapeake Bay	24
			13.5-15.3[c]	mid-Chesapeake Bay	49
			1.0-32.0	Matagorda Bay, Texas	100
	0.0			Virginia tributaries	67
	< 0.5[d]			Delaware estuary	77
		75.0-80.0	< 50.0	Laguna Madre, Texas	92
	> 5.0[c]		10.0-20.0[c]	Delaware River estuary	99
	15.5	45.2		Florida Everglades	83

[a] at temperature > 20°C
[b] peak spawning
[c] spawning
[d] laboratory tests: bay anchovies were unable to survive below 0.5 ppt for extended periods. Mortality: 70% in 4 h at 24°C, 73% in 2 h at 23°C, 30% in 96 h at 10°C.

Table 4. Temperature ranges for bay anchovy.

Life stage	Minimum °C	Maximum °C	Preferred or optimum range	Acclimation °C	Location	Reference
EGGS			13.0-30.0		overall suitable range	
	9.0	31.0	20.0-27.0		upper Chesapeake Bay	24
			27.2-27.8		Beaufort, North Carolina	57
			17.0-25.5		Delaware River estuary[h]	78
			22.0-32.0		Miami, Florida	21
			27.2-27.8		Matagorda Bay, Texas	100
LARVAE			15.0-30.0		overall suitable range	
		40.0[a]		25 (15ppt)	Delaware River estuary	78
			> 11.0		Matagorda Bay, Texas	100
	7.0	31.0			Alazan Bay, Texas	23
	0.0	31.0	23.0-27.0		upper Chesapeake Bay	24
JUVENILES			10.0-30.0		overall suitable range	
	0.0	31.0			upper Chesapeake Bay	24
			26.0-28.0	28	Delaware River estuary	78
			20.0-24.0	24	New Jersey	96
	6.0-15.0			10 and 25	Delaware River estuary	77
		29.0-31.5[b]		19.5 and 24.0		
		31.5-32.0[c]		19.5 and 24.0		
		31.5-32.0[c]		10 and 25		
		31.0-35.0[d]		24.6-31.3	Galveston Bay, Texas	14
		25.0-33.0[d]		15.0-26.4		
		34.0-37.0[e]		summer		
		32.0-35.0[e]		winter		
ADULTS			5.0-30.0		overall suitable range	
		37.0	24.5-32.5		Galveston Bay, Texas	30
	2.2	27.1			Hudson River	25
	10.0[f]			22 (30 ppt)	New Jersey	96
		> 32.0		21 (28 ppt)		
			20.0	15 (29 ppt)		
			27.0		Delaware River	78
			8.1-32.2		Matagorda Bay, Texas	100
		> 40			Galveston Bay, Texas	14
	16.0	34.0			Florida Everglades	83
	> 15.0[g]	30.0	22.0-27.0[g]		Delaware estuary	99
			27.2-27.8[g]		mid-Chesapeake Bay	49

[a] lethal
[b] 48 h LT_{50}
[c] LT_{100}
[d] 3 h LD_{50}
[e] 0.5 h LD_{100}
[f] total mortality at 29 h
[g] spawning
[h] for successful incubation

Table 5. Summary table of on-site entrainment survival studies at a Delaware River power plant.[78]

Life Stage	Initial Survival %	12-h Survival %	24-h Survival %	Delta T °C	Ambient River T °C
Intake Larvae	31.2-87.5	0.0-17.5	0.0-5.0	0.0-14.0	15.0-31.6
Discharge "	0.0-37.2	0.0-16.7	0.0	" "	
Intake Juveniles	75.0-100	0.0-66.0	0.0-30.7	0.0-14.2	10.0-31.6
Discharge "	12.5- 87.4	0.0-48.7	0.1-14.2	" "	
Intake Adults	62.0-84.0	28.0-77.8	1.2-16.9	0.5-14.0	11.5-31.6
Discharge "	35.3-68.2	0.0-50.0	0.0-33.3	" "	