An Ecological Assessment of the Non-Indigenous Isopod, *Synidotea laticauda*, in Delaware Bay

by

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ABSTRACT OF THE THESIS

An Ecological Assessment of the Non-Indigenous Isopod, *Synidotea laticauda*, in Delaware Bay

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Synidotea laticauda is a non-indigenous marine isopod that has been documented in Delaware Bay since 1998. Due to its relatively resent arrive there is a general lack of scientific knowledge about the impact this isopod may have on local ecosystems. Extremely high seasonal abundances, documented over the past three years, suggest the potential for a strong impact. A presence-absence survey conducted during the summer of 2006 documented *S. laticauda* along portions of both the New Jersey and Delaware coasts of Delaware Bay and on several oyster seed beds within the bay. Isopods were only present in portions of the bay containing anthropogenic structures and salinities between 2 and 22. *Synidotea laticauda* were not observed along the Atlantic coasts of New Jersey or Delaware. Temperature-salinity challenges found that *S. laticauda* die quickly in fresh water but can survive in salinities of 30 and 35. The temperature-salinity challenges also found that *S. laticauda* survived in water temperatures typical for Delaware Bay. Although lethargic, isopods experienced very little mortality at 5 ºC; however, high mortality was experienced above 25 ºC. Regular monitoring of recently deployed (clean) and continuously deployed (fouled) cages in the Maurice River identified a preference for structures accumulating biological fouling. Several trophic interactions between *S. laticauda* and the biota of Delaware Bay were also identified in this study. Single-choice feeding trials identified predation on nine fauna and flora species and established *S. laticauda* as an omnivore capable of exploiting multiple food resources within the bay. Furthermore, gut content analyses of fish collected from the Maurice and Nantuxent Rivers indicate that a minimum of four predatory fish species consume *S. laticauda*, although it does not appear to be an important component of their diet. Collectively these findings indicate *S. laticauda* will persist in portions Delaware Bay but with a nominal ecological impact.

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1.0 INTRODUCTION

In 1999, a non-indigenous marine isopod was discovered in the Maurice River, a tributary of Delaware Bay, by a research technician working at Rutgers University Haskin Shellfish Research Laboratory (HSRL) in Bivalve, NJ. Specimens collected from the river were originally identified as *Synidotea laevidorsalis* by the taxonomists John Chapman and James T. Carlton (R. Barber, pers. comm.), who noted a cosmopolitan distribution following the global dispersal of the isopod via sailing vessels over the past two centuries (Chapman and Carlton 1991, 1994). Their interpretation, however, was disputed by Poore (1996) who argued that the *S. laevidorsalis* described by Chapman and Carlton (1991, 1994) was comprised of at least five nominal species in the genus *Synidotea*. Recent molecular analyses suggest that the *Synidotea* species found in Delaware Bay and elsewhere in the USA is *S. laticauda* (R. King 2006, SERTC, pers. comm.).

Synidotea laticauda Benedict, 1897, is a member of the Isopoda suborder Valvifera (Fig. 1.1). This suborder is primarily comprised of benthic marine isopods inhabiting shallow or intertidal environments. A distinguishing feature of the Valvifera is the position of the uropoda, which lie along the pleon and pleotelson, forming opercular valves that fold inward across the body like hinged doors covering the pleopoda within the branchial chamber (Miers 1881; Richardson 1904). *Synidotea* is the most species rich genus within the Family Idotea, and most are found in boreal and Arctic waters of the northern Pacific, with a few species occurring in the Indo-West Pacific and the western Atlantic (Schultz 1969; Poore 1996). *Synidotea laticauda* is endemic to the shallow intertidal waters of California (Benedict 1897; Schultz 1969) and was reported by

Menzies and Miller (1972) to be geographically and ecologically segregated in the San Francisco Bay system.

This study represents the first ecological assessment of the non-indigenous occurrence of *Synidotea laticauda* in Delaware Bay. Delaware Bay is a shallow, cone shaped estuary, located along the Atlantic coastal plain of the USA, within the multi-jurisdictional boundaries of Delaware, Pennsylvania, and New Jersey (Fig. 1.2). In addition to *S. laticauda*, records compiled from the United States Geological Survey database on aquatic non-indigenous species indicate that at least 25 estuarine species present in the Delaware estuary are non-indigenous (USGS 2007).

Synidotea laticauda was likely introduced to Delaware Bay through the discharge of ballast water from ships visiting the region. Ballast water is one of many mechanisms considered important in initiating biological invasions (Carlton and Geller 1993; Wonham et al. 2000) and Delaware Bay receives more than 3,000 port calls each year from commercial vessels (Hull et al. 1986). Ballast water is pumped aboard ships to provide stability during transit and leads to an exchange of water between subsequent ports of call. Small aquatic organisms can be pumped with water into a ships ballast tanks in one location and discharged in a second locality where the organisms may disperse and invade new habitats.

The study of biological invasions, including ballast water as a vector for dispersal, began in earnest following Charles Elton’s (1958) seminal book on the topic. Non-indigenous species are now recognized throughout the world, including aquatic ecosystems in the Mediterranean (Galil 2000; Flagella and Abdulla 2005; Gollasch 2006), Baltic Sea (Leppäkoski et al. 2002), Hawaii (Coles et al. 1998; Eldredge and

Carlton 2003), San Francisco Bay (Cohen and Carlton 1998; Ranasinghe et al. 2005), and Chesapeake Bay (Ruiz et al. 1999). Prior to the advent of agriculture and trade, natural dispersal was the only method available for biota to expand their range to contiguous geographical regions. Ecological, climatic, and physical barriers encountered by biota restrict the rate and breadth of such dispersal (Mooney and Drake 1987; Ruiz et al. 1997). For example, water temperature, salinity, and depth can act as major barriers in the movement of organisms among the world's oceans (Odum 1959). However, the industrial and migratory behavior of humans over the past 500 years has accelerated and circumvented many dispersal barriers, leading to the appearance of non-indigenous species in distant geographical regions (Mack et al. 2000). Today, many organisms can be rapidly transported great distances due to advances in shipping and other forms of transportation (Carlton 2003).

Terminology used to describe non-indigenous species is inconsistent and often ambiguous. Many of the terms used by scientists and the media overlap and are often used interchangeably. Examples include non-native, exotic, nuisance, introduced, and non-indigenous species (US Congress 1993; Federal Register 1999). For the purposes of this study, the term non-indigenous species will be used to refer to the accidental or intentional release of a species into a geographical region that has not historically been occupied by that species, resulting in the establishment of a self-sustaining population without additional human assistance (Carlton 2003).

Although an estimated 50,000 non-indigenous species have been introduced to the United States, intentionally or unintentionally, only a fraction are considered invasive Executive Order 13112, signed by President Clinton in 1999, defined non-indigenous species as invasive if they "cause or are likely to cause economic or environmental harm or harm to human health'. Pimentel et al. (2005) estimated the costs associated with the mitigation and control of non-indigenous species in the United States at $120 billion/yr. These costs do not reflect the ecological impacts. Negative ecological impacts of non-indigenous species can include changes to the dynamics of natural populations and the potential introduction of genetic effects through hybridization. The presence of non-indigenous species may alter trophic dynamics, modify local geography, and change the availability of nutrients and primary production within a community (Vitousek 1990; Parker et al. 1999). Entire ecosystems have been altered by the presence of a non-indigenous species. Examples include the arrival of the common European periwinkle (*Littorina littorea*) on the rocky coast of North America between Nova Scotia and Long Island in the 1840's (Bertness 1984) and the introduction of the Nile tilapia (*Oreochromis niloticus*) to the Great lakes of Africa (Lowe-McConnell 1993).

Despite the near ubiquity of non-indigenous species throughout the world, the majority of introductions ultimately fail. Many species only become established following repeated introductions, while others that appear to succeed initially may become locally extinct within a few generations (Mack et al. 2000; Sax and Brown 2000; Simberloff and Gibbons 2004). Biological invasion is a systematic process with each step dependent on the success of the previous step (Fig. 1.3). Physical and environmental barriers are frequently encountered throughout the process and can lead to the failure of any step causing the entire invasion to halt. A biological invasion begins when members of a species are successfully transported from a donor region to a novel recipient region. Those that survive this process must establish a local, self-sustaining, population within the recipient region. This may initially consist of only a few individuals and may be confined to a small geographical region. Once established, non-indigenous species may experience a lag in population growth until circumstances such as the availability of food resources and climatic conditions are favorable. Under favorable conditions, non-indigenous species may experience local range extension, particularly if a competitive advantage exists over co-occurring biota, such as the lack of natural predation or a faster growth rate. For example, the fast growing, thicker shell of the veined Rapa Whelk allows it to reach a size refuge from predation ahead of native whelk species in the Chesapeake Bay (Harding 2003). An increase in range and population can lead to a local ecological impact as interspecific interactions and demand for resources increase. Humans often overlook these impacts until they cause negative economic consequences, harm human heath, or damage aesthetics (Mack et al. 2000; Kolar and Lodge 2001; Sakai et al. 2001).

When non-indigenous species successfully establish self-sustaining populations, the consequences for the recipient geographical region and ecosystem can be positive, negative, or neutral. Negative consequences typically garner the greatest scientific and media scrutiny. An ecological assessment of a non-indigenous species, initiated early in its invasion, would help identify probable ecological risks associated with its introduction before developing into a significant problem. Government agencies and other stakeholders would be better informed to design and implement an appropriate response on the basis of scientific evidence (EPA 1992; NISC 2003). It is not feasible to manage every non-indigenous species that is detected and therefore an ecological assessment helps determine which species require urgent action, which require monitoring, and which do not require immediate attention (NISC 2003).

Synidotea laticauda has been documented in Delaware Bay over several years indicating that the species has successfully established itself (Bushek and Boyd 2006). Its ecological and economic impact, as well as its potential to spread throughout Delaware Bay and the Mid-Atlantic coast remains unknown. Bushek and Boyd (2006) describe *S. laticauda* (mistakenly identified as *S. laevidorsalis*) as having extremely high localized seasonal abundances, with isopods conspicuously abundant on ropes and buoys in the water column. Due to the high seasonal abundances, the isopod could have a strong impact on the local ecosystem. Therefore, an ecological assessment of *S. laticauda* in Delaware Bay and adjacent waters was warranted and provided the impetus for this study. The next chapter addresses the spatial distribution of *S. laticauda* in Delaware Bay and adjacent waters, relating distribution to temperature and salinity tolerance and biological fouling of anthropogenic structures. In chapter III, potential trophic interactions between *S. laticauda* and selected biota of Delaware Bay are examined. Overall, this study assesses the impact of *S. laticauda* in the Bay and determines if it should be considered invasive in the region.

Figure 1.1 *Synidotea laticauda***.** Photo credit: Southeast Regional Taxonomic Center (SERTC)

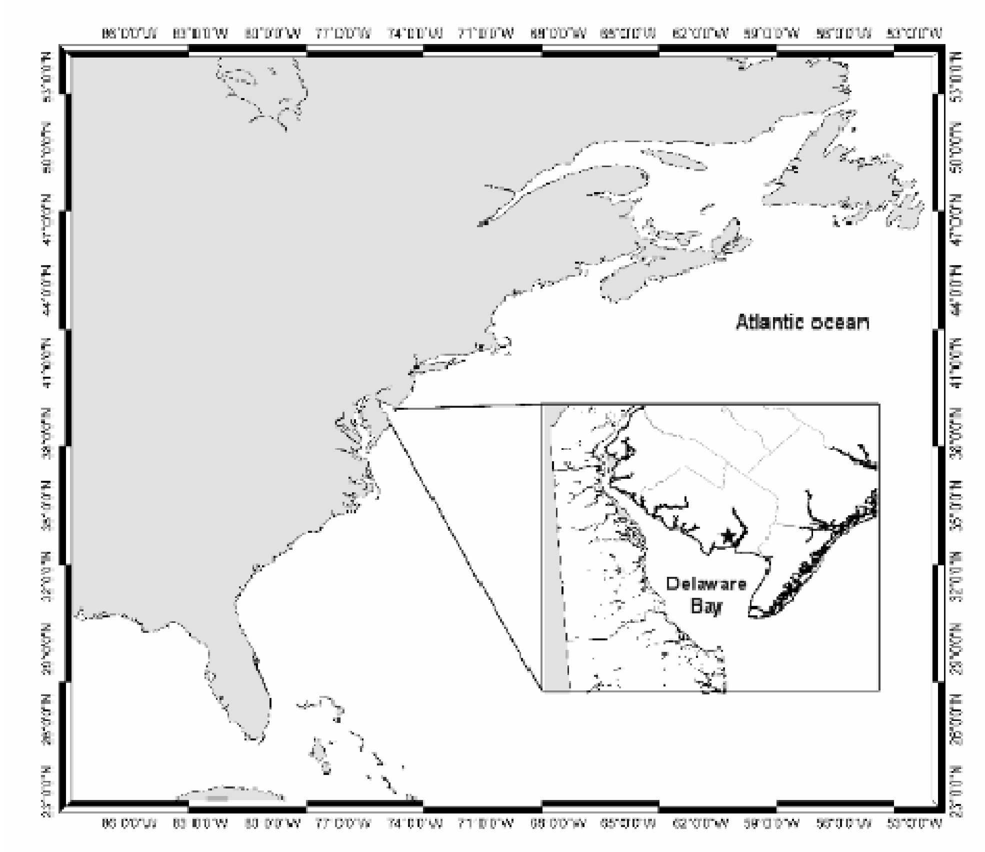

Figure 1.2 Map of Delaware Bay, USA. The Rutgers University Haskin Shellfish Research Laboratory is located in Bivalve, NJ and indicated by the ★

Biological Invasion

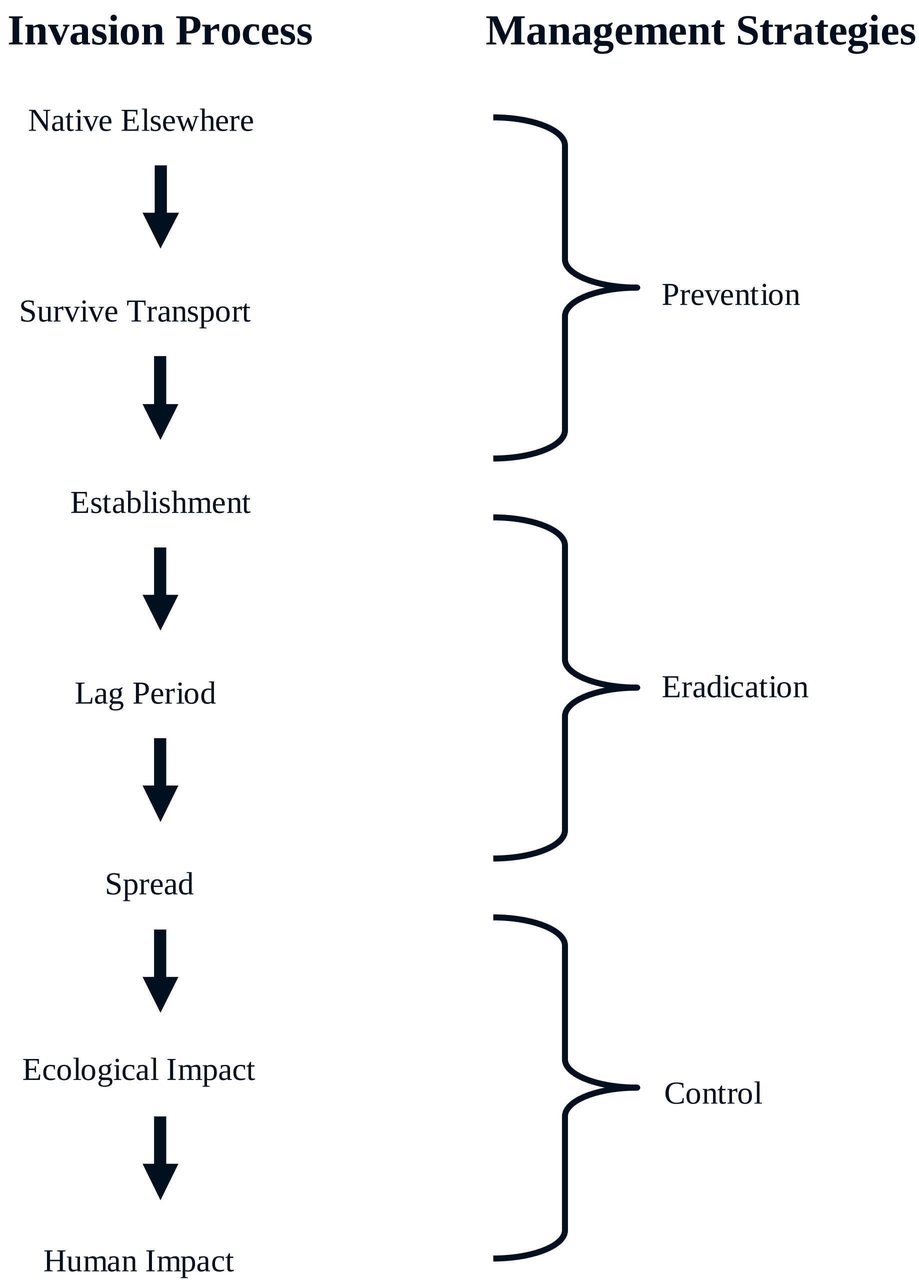

Figure 1.3 The biological invasion process. Left column: systematic steps involved in an invasion. Right column: management strategies available to limit the invasions success (Modified from Sakai et al. 2001).

2.0 DISTRIBUTION OF *S. LATICAUDA*

2.1 INTRODUCTION

The current distribution of *S. laticauda* in Delaware Bay has not been fully evaluated. Initial investigations by Bushek and Boyd (2006) indicated that the isopod is present in the bay, although likely confined to mesohaline portions of the estuary and typically associated with heavily fouled anthropogenic structures. This study did not evaluate the adjacent coast of Delaware or the Atlantic coast of New Jersey and lead to questions about the impact of temperature and salinity and the role of biological fouling on the distribution of *S. laticauda* in Delaware Bay and the likelihood of its spread beyond the bay.

Temperature and salinity represent two fundamentally important ecological parameters for aquatic invertebrates, which can directly affect an organism's survival, development and reproduction, while indirectly affecting parasitism, disease resistance, and predation (Krebs 1985). If either parameter becomes too extreme or an organism is unable to compensate for shifts in temperature or salinity the likely outcome will be death (Vernberg and Vernberg 1975). Temperature and salinity are synergistic. Either parameter is capable of affecting an organism's biological response to the other, potentially resulting in a shift, a contraction, or an expansion of the tolerance range for that organism (Kinne 1964).

The present study addresses the distribution of *S. laticauda* in Delaware Bay and adjacent waters with a presence-absence survey. *In vitro* temperature-salinity challenges address the hypothesis that temperature and salinity restrict the range of *S. laticauda* in Delaware Bay. Finally, biologically fouled and non-fouled cages were monitored weekly to evaluate the hypothesis that *S. laticauda* have a preference for biologically fouled structures.

2.2 MATERIAL AND METHODS

2.2.1 Presence-Absence Survey

A presence-absence survey was conducted from June to September 2006 to establish the range of *S. laticauda* in Delaware Bay and the adjacent waters of New Jersey and Delaware (Fig. 2.1). Survey sites were associated with anthropogenic and natural habitats located within several tributaries, oyster seedbeds, inlet bays, and canals. Specifically, marinas, boat ramps, bridges, riverbanks, beaches, ropes, and buoys were visually inspected for *S. laticauda.* Sites in Delaware Bay were located between Pennsville, NJ (39º 38' 27" N 75º 32' 45" W) and Bowers Beach, DE (39º 03' 29" N 75º 23' 53 W). The Atlantic coast of New Jersey was surveyed between Liberty State Park (40º 41' 41" N 74º 03' 40" W) and Cape May (38º 56' 44" N 74º 53' 54" W). The Atlantic coast of Delaware was surveyed south of Delaware Bay between Lewes (38º 47' 15" N 75º 09' 41" W) and Indian Bay (38º 34' 50" N 75º 05' 12" W).

The specific sites selected and the survey methods used were based on accessibility. Tides were not considered when selecting or visiting specific survey sites. For sites accessible by land, a 12 x 6 cm aquarium dip net (1.5-mm mesh) was repeatedly swept along submerged structures below the water, down to a depth of 0.5 m. A four-foot PVC extension was attached to the end of the net when needed. Whenever possible, submerged ropes, buoys, and other debris located within anthropogenic survey sites were inspected for *S. laticauda*. Submerged rocks, shells, and vegetation were inspected within natural habitat survey sites.

For sites located in the open waters of Delaware Bay, researchers working from the New Jersey Department of Environmental Protection (NJDEP) R/V *Zephyrus* and the Delaware Department of Natural Resources and Environmental Control (DNREC) R/V *First State* reported the presence of *S. laticauda* on ropes, buoys, shell bags, and cinder blocks retrieved as part of their monthly monitoring program for oyster recruitment. Finally, channel markers within the Atlantic Intracoastal Waterway (ICW) were surveyed from the HSRL R/V *Veliger*. When sampling from the R/V *Veliger*, submerged portions of buoys and pilings supporting ICW channel markers were scraped with a 40 x 30 cm bait net (6.3-cm mesh) to collect fouling organisms which were subsequently inspected for *S. laticauda.*

Geographic coordinates for shore-based and ICW survey sites were determined with a Magellan GPS Tracker. Water temperature and salinity were measured with a hand-held alcohol thermometer and a refractometer, and the biota and topography noted. Geographic coordinates for Delaware Bay sites were obtained from the Delaware Bay oyster recruitment monitoring program. Researchers participating in this program measured water temperature and salinity with either a YSI 85 or a hand-held alcohol thermometer and refractometer. Presence or absence of *S. laticauda* at a survey site was scored as positive (+) if the isopod was observed or negative (-) if no individuals were found. The geographic coordinates and presence-absence score for each survey site were plotted with ArcMap V.9.2®.

2.2.2 Temperature and Salinity Tolerance

Acute temperature-salinity challenges assessed the ability of *S. laticauda* to survive an array of temperature and salinity regimes associated with Delaware Bay. Four trials in total were conducted. The first two trials measured the survival of adult *S. laticauda* at 4-h intervals in various temperature-salinity regimes for 48 h. The other two trials measured the survival of juvenile *S. laticauda* in various temperature-salinity regimes after 24 h.

Synidotea laticauda used in the challenges were collected from plastic mesh oyster bags maintained by the Bayshore Discovery Project (BDP) near the mouth of the Maurice River (39º 13' 58" N 75º 01' 57" W). Collection of the adult isopods for the first trial was on October 8, 2006, while those used in the second trial were collected November 4, 2006. Both groups of adult *S. laticauda* were held in a 10-l aquarium containing unfiltered Maurice River water (18 to 20 °C and salinity 20) with continuous lighting and aeration for 72 h prior to the start of their respective trials. The juvenile *S. laticauda* used in the third and forth trials were obtained from gravid females collected from the Maurice River on June 3 and 25, 2007, respectively. Gravid females were held up to a week in individual Carolina culture dishes® containing 200-ml of unfiltered river water (20 ºC and salinity 20). Dishes received complete water changes every other day with *Ulva* sp. supplied *ad libitum* as food. Dishes were checked daily for recently released juveniles. Juveniles were gently transferred with a wide-mouth pipette to a second dish containing only siblings and were maintained under the same conditions as the gravid females until the start of each trial.

2.2.2.1 Adult Isopod Challenges

Six experimental salinity treatments (0, 5, 15, 25, 30, and 35) were prepared by adjusting the salinity of water collected from the Maurice River (approx. salinity = 18) with Instant Ocean ® or DI water. Untreated HSRL domestic well water represented the freshwater treatment. Twenty liters of each treatment were filtered to 5 µm with a GE Smartwater® filter and stored in covered plastic buckets until needed (< 1 week). A hand-held refractometer verified treatment salinities.

Experiments were conducted in Carolina Culture dishes® filled with 200-ml of water from one salinity treatment, then distributed among constant temperature chambers such that each temperature chamber received three replicates of each salinity treatment. Two trials were completed using different temperature-salinity combinations to provide a broad range of treatments. The first adult isopod trial consisted of four salinity treatments (0, 5, 15, 25) at five temperatures (5, 11, 21, 25, 30 ºC) creating a 4 x 5 factorial. However, multiple dishes in the 5 ºC and 10 ºC chambers were compromised when water and isopods were inadvertently spilt. Based on the results of the first adult trial, a second adult trial was conducted to complete the missing cells of the factorial and to examine the effects of a higher temperature (35 ºC) and salinity (35) on isopod survival (Table 2.1). Thus, the second adult trial consisted of six salinities (0, 5, 15, 25, 30, 35) and three temperature treatments (5, 11, 35 ºC) creating a 6 x 3 factorial. These treatments were selected to approximate or exceed the extremes that isopods may experience in Delaware Bay.

To initiate the experiments, isopods from the aquarium were randomly dispersed to dishes so that each dish contained six isopods. During the experiments, dishes were stacked vertically to prevent evaporation and food was withheld to prevent fouling of the water. A hand-held alcohol thermometer measured chamber temperatures and the salinities were checked periodically with a refractometer. Adult isopods in both trials remained in the temperature-salinity treatments for 48 h. Isopod viability was assessed every 4 h by direct examination according to criteria modified from Kivivuori and Lahdes (1996). Specifically, isopods exhibiting no movement after three prods with a metal probe were scored as dead. In addition to swimming, movement of either antennae or pereopoda resulted in scoring the individual as live (Kensley and Schotte 1989).

The mean proportion of adult *S. laticauda* alive at each 4-h interval was calculated for each temperature-salinity treatment. For analysis, results of the two trials were combined into a single factorial. Therefore, treatments performed in both trials contained six replicates, while all other treatments consisted of three replicates (Table 2.1). The effect of temperature and salinity on the rate of isopod mortality was evaluated graphically. Specifically, the proportion of live isopods at each 4-h interval was plotted for each temperature-salinity combination and the response curves compared visually.

2.2.2.2 Juvenile Isopod Challenges

Two 20-l carboys of water were prepared at HSRL. The first carboy contained water from the Maurice River that had its salinity increased from 15 to 35 with the addition of Instant Ocean®. The second carboy contained untreated freshwater from the HSRL domestic well. Both carboys were filtered to 5 µm with a GE Smartwater® filter and stored at room temperature until needed (< 1 week).

Experimental salinity treatments were prepared at Rutgers University Institute of Marine and Coastal Sciences (IMCS) by combining the adjusted Maurice River water and freshwater contained from the carboys to obtain desired salinities. Six salinities were used in the first juvenile trial (0, 5, 10, 25, 30, and 35). The 25 salinity treatment was replaced with a 20 salinity treatment in the second trial because it better approximated the salinity at which the isopods were acclimated. Salinities in the second juvenile trial were 0, 5, 10, 20, 30, and 35. All salinities were verified with a Thermo Orion model 105 salinity meter.

Experiments were conducted in six-well culture plates (BD Falcon™ Cat. # 35 1146). Each well was filled with 12-ml of one salinity treatment such that each plate contained one well of each salinity. Three hundred juvenile *S. laticauda* per trial were dispersed among the treatments (1 isopod per well) such that 10 isopods were exposed to each temperature-salinity regime. Juveniles in the first trial were selected at random from a pool of 547 *S. laticauda* released by eight gravid females (Table 2.2). Juveniles in the second trial were selected at random from 415 *S. laticauda* released by eight additional gravid females. The mean post hatching age of the juveniles used for the first trial was 4 (± 2.9) days, while juveniles in the second trial were 1.6 (± 0.7) days old. Culture plates were distributed among five temperature chambers (4, 10, 25, 33, and 37 °C) at IMCS. During these experiments plastic lids prevented evaporation and food was withheld to prevent fouling of the water. Portable digital loggers recorded chamber temperatures

Isopods remained in temperature-salinity treatments for 24 h, after which direct observation assessed the number of live and dead isopods in each treatment. For the first trial, observations were made on a bench top without magnification while illuminating each isopod with a dissecting microscope illuminator. To confirm observations, these isopods were acclimated at room temperature (approx. 20 ºC) for 24 h and then re-assessed under the assumption that several may be lethargic, particularly at cooler temperatures. Due to increased mortality during the recovery period the isopods in the second trial were assessed only at 24 h, but with a dissecting microscope at 24 x magnification to improve determination of viability.

Isopods in both trials were scored as alive or dead following criteria modified from Kivivuori and Lahdes (1996) as described for the adults. The salinity of each well was measured at the end of the challenges to ensure no changes had occurred. Isopods were preserved in 70 % ethanol then measured (head to telson) to determine size distribution.

The mean proportion of juvenile *S. laticauda* alive after 24 h was calculated for each temperature-salinity treatment. The proportion of live isopods was also calculated for each temperature-salinity treatment following the 24 h recovery period in the first juvenile trial. The relationship between temperature and salinity and isopod survivorship was examined for both juvenile trials with interaction plots that measured the mean proportion of live isopods across salinities for each temperature treatment.

2.2.3 Biological Fouling Association

The affinity of *S. laticauda* for biologically fouled substrate was evaluated by comparing the abundance and size of isopods accumulating on biologically fouled (bio-fouled) and non-fouled (cleaned) submerged structures. Wire-mesh cages (cages) were deployed in the Maurice River and sampled weekly for *S. laticauda* and co-occurring motile species. One set of cages (N=3) was allowed to accumulate bio-fouling while another set (N=3) was kept clean.

Cages were constructed of 13-mm PVC coated wire-mesh, secured with plastic cable-ties; forming 13 x 13 x 13 cm^3 cages (Fig. 2.2). The top panel, fastened with a removable wire clip, functioned as a door, and the inside bottom panel was covered with 1-mm plastic mesh to prevent isopods from escaping while the trap was being retrieved. A single stone and two oyster shells (*Crassostrea virginica*) were placed inside each cage to provide additional structure and weight. Ropes secured to the dock located at HSRL, held each cage approximately 15 cm above the river bottom. Cage position was randomized weekly. To maintain the non-fouled treatment two sets of clean cages were rotated weekly between samplings. Between rotations, cleaned cages were scrubbed in hot freshwater and desiccated in the sun to eliminate biological fouling.

Cages were deployed from June 14 to August 16 2006, and denuded weekly of motile species. *Synidotea laticauda* were sorted from the other motile species, enumerated, weighed, and the total length (head to telson) of up to 30 randomly selected individuals was measured with digital calipers. Weekly abundances were plotted to determine seasonal patterns. Analysis of variance (ANOVA) was used to identify significant effects of date and treatment on abundance and length. Other motile species from each replicate were sorted, enumerated, and weighed by taxon to compare temporal changes in abundances with isopod abundances.

2.3 RESULTS

2.3.1 Presence-Absence Survey

A total of 117 sites throughout Delaware Bay and the adjacent waters of New Jersey and Delaware were surveyed for *S. laticauda* during the summer of 2006 (Table 2.3 through 2.7). *Synidotea laticauda* were found at 34 sites in Delaware Bay or within its tributaries which contained submerged anthropogenic structures (Fig. 2.3). Isopods were typically found clinging to biologically fouled rope, buoys, Styrofoam, and wood structures in the water. Marinas and boat launches were the most frequent locations along the coast of Delaware Bay to have *S. laticauda* present. A small number of isopods were found among biologically fouled concrete blocks at the East Point Lighthouse. Salinities at the Delaware Bay sites ranged from 0 to 27, with most below 20 and the lowest levels occurring furthest up the tributaries. *Synidotea laticauda* were mostly present in salinities of 5 to 21, but isopods did occur at three sites with salinities < 5 (Table 2.3) and four sites with salinity > 21 (Table 2.4). A small number of isopods were observed clinging to biologically fouled boat bumpers in the Delaware City Branch Canal at the Fort DuPont State Park and the nearby Delaware City Marina. In addition, a few *S. laticauda* were present on ropes and floating debris at the River Road Marina in the Maurice River, NJ. Although *S. laticauda* were abundant downstream of the River Road Marina they were not present in freshwater sections of the river upstream of the marina. Likewise, *S. laticauda* were found near the entrances of Bidwell Creek, Dividing Creek, Nantuxent Creek, and the Cohansey River, but were not found in the freshwater sections of these tributaries. Researchers from HSRL and DNREC reported *S. laticauda* from 15 locations in Delaware Bay between June and October, 2006 (Table 2.4). Isopods were always found clinging to ropes and shellbags that had been deployed to monitor oyster recruitment. These locations fell within the region encompassed by those sites along the coast and tributaries where *S. laticuada* were observed (Fig. 2.3). The absence of isopods, their presence on other structures, and the composition of co-occurring species were not reported by these observers. Species routinely identified with *S. laticauda* in Delaware Bay and its tributaries included grass shrimp (*Palemonetes* sp.), amphipods (Gammaridea), cabbage grass (*Ulva* sp.), Atlantic ribbed mussel (*Geukensia demissa*), mud crab (*Panopeus* spp.), and various juvenile fish.

Synidotea laticauda was not found along the Atlantic coasts of New Jersey or Delaware. Sites along the New Jersey coast included several coastal bays and their tributaries with salinity from 0 to 30 (Table 2.5), as well as a 150-km section of the ICW (Table 2.6). Note that salinity often exceeded 25, which was greater than most sites within Delaware Bay. The ICW channel markers surveyed for *S. laticauda* were located near salt marshes and in areas containing anthropogenic structures, such as docks and bulkheads. Biota frequently observed along the Atlantic coast of New Jersey included the isopod *Ligia oceanica,* green sea urchin (*Strongylocentrotus droebachiensis*), common sea star (*Asterias* sp.), grass shrimp, blue crab, Atlantic ribbed mussels, various tunicates, and red and green algae. Finally, the Atlantic coast of Delaware was surveyed in four back bays on August 19, 2006 but no isopods were found among the docks, buoys, artificial reefs, and submerged vegetation surveyed (Table 2.7). Note that salinity was 29 – 30 at these sites.

2.3.2 Temperature and Salinity Tolerance

2.3.2.1 Adult Challenges

Several problems confounded the adult temperature-salinity trials. First, one isopod was cannibalized in each of 13 dishes and two isopods were cannibalized in another three dishes. Cannibalized *S. laticauda* were partly consumed or entirely absent from the dish with only a few body segments remaining. These isopods were not included in further analysis because it was unclear whether or not their deaths were due to the experiment treatment or predation by the other isopods. Second, the thermostat on the 35 ºC treatment failed, increasing the temperature above 40 ºC and killing all isopods. In addition, the 40 hr time period was not recorded during the first isopod trial. Finally, neither trial contained a complete factorial so several treatments were missed. Despite these problems, data were collected and are reported here.

Mortality of adult *S. laticauda* was most conspicuous among isopods placed in the 0 salinity treatments (Table 2.8); only a single isopod from the 25 ºC treatment was alive at 48 h. Most mortality in the zero salinity treatments occurred within the first 24 h, with the highest mortality occurring in the 5 ºC and 11 ºC treatments (Fig. 2.4). Complete mortality also occurred in the 5 salinity 30 ºC treatment. Isopod survival was considerably higher for the remaining temperature-salinity treatments, with five treatments experiencing no mortality (Fig. 2.5 – 2.7). Overall, these data indicate adult *S. laticauda* are relatively tolerant to a wide range of temperature and salinity.

2.3.2.2 Juvenile Challenges

Juvenile *S. laticauda* were much more sensitive than adults to acute changes in temperature and salinity. All of the *S. laticauda* in the first juvenile temperature-salinity challenge placed in the 37 ºC treatments and all but one each in the 0 salinity and 5 salinity treatments were scored as dead following the 24-h acute exposure (Table 2.9). Two temperature-salinity treatments (4 ºC and 25 salinity, 10 ºC and salinity 35) had no mortality. In general, survival was greater at higher salinity and cooler temperatures, with the highest overall survival rates occurring at a salinity of 25 (Fig. 2.8). The proportion of isopods scored alive changed in a number of the temperature-salinity treatments following the 24-h recovery period (Table 2.9 [brackets]). Two of the temperature-salinity treatments (25 ºC and salinity 0, 4 ºC and salinity 10) had an increase in the number of live isopods from their initial scoring at 24 h, and 10 other treatments had a decrease in the number of live isopods.

Results for the second juvenile trial were similar to the first. All of the isopods placed in the 37 ºC treatments, all but one in 0 salinity treatments, and all but two in 5 salinity treatments were dead within 24 h (Table 2.10). Additionally, nearly all died in the 30 ºC treatments. No mortality occurred in temperature-salinity regimes of 20 ºC and salinity 10 or 10 ºC and salinity 20. In general, survival was highest at moderate temperatures (10 ºC to 20 ºC) and moderate to high (10 to 30) salinity (Fig. 2.9).

2.3.3 Biological Fouling Association

Mean water temperature and salinity during cage sampling were 26.1 °C (± 5.7 SE) and 9 (± 6 SE), respectively. Temperature increased steadily during the first four weeks, stabilizing at about 28 ºC thereafter (Fig. 2.10). In contrast, salinity decreased from 15 to 10 in the third week and remained around 9 until the last two weeks, when it rose to 15. Based on the temperature-salinity experiments just described these conditions were suitable for *S. laticauda*.

During this period, weekly sampling indicated that *S. laticauda* were more abundant on cages accumulating bio-fouling (Fig. 2.11), particularly during the first half of the experiment, when isopod abundance gradually increased (Fig. 2.12). The only period when there were significantly more isopods on clean versus fouled cages was in the first week of the experiment before much fouling had accumulated. The mean number of isopods on the bio-fouled cages was 95.7 (± 13.2 SE) and 62.4 (± 5.4 SE) on cleaned cages, but these numbers fluctuated considerably and a dramatic decline in abundance occurred on July 19, 2006 for the fouled cages. An ANOVA of treatment effect on *S. laticauda* abundance found a significant difference between treatments and a significant effect of sampling date on isopod abundance, but there was no significant interaction between treatment and date (Table 2.11). The decline in *S. laticauda* abundance on July 19, 2006 coincided with an increase in mud crab (*Panopeus* sp.) abundance on the same date (Table 2.12). Mud crabs and grass shrimp (*Palaemon* sp.) were the most common co-occurring fauna collected but were typically an order of magnitude less abundant than the isopods. Other co-occurring fauna included blue crab (*Callinectes sapidus*), toadfish (*Opsanus tau*), naked gobi (*Gobisoma bosc*), and amphipods (Table 2.12).

A gradual increase in the size of the isopods occurred from June 14 to July 26 (Fig. 2.13). An ANOVA of the treatment effect on isopod size found a difference in size between treatments, independent of sampling date (Table 2.13). The mean size of isopods on the cleaned cages was slightly greater (8.6 mm ± 0.09 SE) than on the fouled cages (8.3 mm ± 0.08 SE) (Fig. 2.14).

2.4 DISCUSSION

This study provides the most comprehensive assessment of *S. laticauda* distribution in Delaware Bay and adjacent waters to date. *Synidotea laticauda* were present throughout Delaware Bay along both the New Jersey and Delaware coasts and on several of the Delaware Bay oyster seed beds. Interestingly, *S. laticauda* were not observed along the Atlantic coasts of New Jersey or Delaware. *Synidotea laticauda* were consistently associated with anthropogenic structures, such as ropes and buoys and rarely found associated with natural structures. Temperature-salinity challenge experiments involving adult and juvenile isopods identified optimal temperature (10-25 ^{o}C) and salinity (10-30) tolerances. Routine monitoring of experimental cages found a preference for structures accumulating biological fouling. It is possible with these findings to interpret the current distribution of *S. laticauda* in Delaware Bay and to anticipate circumstances in which their distribution may expand in the future.

Synidotea laticauda currently occur in two Atlantic coast estuaries of the United States. In addition to Delaware Bay, they are reported in the Stono River of South Carolina (D. Knott, SCDNR pers. communication). The two populations are geographically separated by nearly 1,000 km and researchers from a number of academic institutions between New Jersey and South Carolina did not report the occurrence of the isopod near their respective institutions when contacted by Bushek and Boyd (2006).

Although the distribution of *S. laticauda* in South Carolina has not been studied, the presence-absence survey conducted as part of this study indicates that *S. laticauda* only occurs in specific regions of Delaware Bay. In particular, they are present in mesohaline and oligohaline regions of the estuary, but do not occur in adjacent Atlantic coastal waters or in the freshwater portions of tributaries draining into the bay. Relatively few isopods are present at the lowest salinities (2-3) while most isopods occur in portions of the bay with salinities of 10 to 24

Menzies and Miller (1972) report *S. laticauda* as a relict estuarine species from the San Francisco Bay system, where they are restricted to the mesohaline and oligohaline portions of the estuary. Although they occurred in salinities of 1 to 25, the highest abundances were reported from the upper mesohaline portions of the San Francisco Bay system.

Salinities in Delaware Bay gradually increase from 0 to 30 between the Delaware River and the mouth of the bay located between Cape May, NJ and Cape Henlopen, DE. Several tributaries drain into the bay and influence the formation of isohalines, especially with extreme drought and rain events (Smullen et al. 1983; Sharp 1988). The observed distribution of *S. laticauda* over the salinity gradients within the bay corresponds with the results of the acute temperature-salinity challenges. Both adult and juvenile isopods experienced near total mortality in the freshwater treatments. This implies that the absence of *S. laticauda* from the low salinity portions of the bay, particularly in its tributaries or near the Delaware River is due to a lack of tolerance towards freshwater. Mortality within the freshwater treatments of the temperature-salinity challenges was rapid. This indicates that environmental conditions, such as a heavy rain event, that could quickly lower salinity could be lethal to isopods in portions of the bay near freshwater inputs and runoff.

While isopod survival was greater in the temperature-salinity challenges at the higher salinities, isopods were absent from the higher salinity regions of Delaware Bay as well as back bays along the Atlantic coasts of New Jersey and Delaware. One possibility is the lower survivorship of juvenile isopods at the higher salinities. Therefore, if adult *S. laticauda* do occur in portions of the bay with higher salinities they are less likely to establish successive generations there because of the sensitivity of juvenile *S. laticauda* to the higher salinities.

Synidotea laticauda occurs most often in the warmer waters of San Francisco Bay (Menzies and Miller 1972). The presence-absence survey was conducted throughout the summer when temperatures in Delaware Bay were at their peak and isopods were found at sites with temperatures of 20 to 31 ºC. Bushek and Boyd (2006) reported *S. laticauda* abundance as seasonally impacted. The abundance of the isopods decreases in September and October and they virtually disappear once the water temperature decreases below 10 ºC, returning in the spring when the water temperatures exceed 10 ºC.

Delaware Bay is a well-mixed estuary and exhibits little variation in water temperature with depth or locality and ranges seasonally from - 2 to 28°C (Sharp 1988). *Synidotea laticauda* are poikilotherms and as such their level of activity is affected by temperature. Adult isopods maintained in the 5 ºC and 10 °C experimental treatments were far less active than isopods maintained at warmer temperatures. Swimming was not observed and there was no noticeable movement of the legs or antennae. Juvenile isopods in the 4 ºC and 10 ºC treatments were less active after 24 h. The ability of *S.*

laticauda to tolerate lower temperatures was anticipated. Members of the genus *Synidotea* originate from the cooler waters of the north and south Pacific, in addition to northern portions of the Atlantic (Moore 2004). In years of warmer, dryer weather, the water temperature in the Bay could increase above the average high of 28 °C (Sharp 1988). This high is already hovering around the upper lethal limit of 25 to 30 °C and exceeding it would likely result in high mortality of these isopods regardless of the salinity.

The present study also demonstrated a preference for biological fouling. However, *S. laticauda* were not the only fauna documented on the experimental cages accumulating biological fouling. Similar to many other locations throughout Delaware Bay, *S. laticauda* was routinely found to co-occur with shrimp, crabs, and amphipods. However, native species of isopod, such as *Idotea baltica*, were seldom observed.

The apparent attraction of *S. laticauda* to anthropogenic structures in Delaware Bay is likely due to the development of trophic interactions with co-occurring species. The trophic dynamics of *S. laticauda* in San Francisco Bay have not been investigated. Menzies and Miller (1972) speculate that *S. laticauda* may consume locally occurring bryozoans and hydroids from California. Like the population in San Francisco Bay, isopods in Delaware Bay were frequently associated with bryozoans and other fouling organisms. *Synidotea laticauda* may be exploiting a niche not occupied by native isopods species. Specifically, *S. laticauda* may utilize bio-fouling habitats for food resources, or they may take advantage of the habitat to avoid predators. The next chapter discusses potential trophic interactions in more detail.

Long term monitoring of *S. laticauda* in the bay could be established utilizing the findings of this study. For example, fouling plates placed in areas of the bay would be ideal for monitoring the distribution and abundance of *S. laticauda.* They require minimal monitoring (perhaps on a monthly basis) and would acclimate bio-fouling. The number of regimes in the temperature-salinity challenges could be increased and examined over a longer period. Interpretation of the temperature-salinity challenges would benefit from a complete factorial design, and the addition of more isopods would allow for stronger statistical analysis. Isopod cannibalism was unexpected in the adult trials. Amending the methodology so that only one isopod was present in a well eliminated the risk of cannibalism.

In conclusion, these findings have established the distribution of *S. laticauda* in Delaware. Both the presence-absence survey and the temperature-salinity challenges supported the hypothesis that temperature and salinity have an impact on *S. laticauda* distribution in Delaware Bay. Results from the bio-fouled and cleaned cage monitoring support the hypothesis that there is a preference by *S. laticauda* for bio-fouled surfaces.

Table 2.1 Adult *S. laticauda* temperature-salinity challenge experiments. Left column is the first trial and right column is the second trial. + indicates temperature-salinity treatment completed, - indicates temperature-salinity treatment not attempted, * indicates that temperature-salinity treatment was attempted but not completed.

	Salinity					
Temperature	**0**	**5**	**15**	**25**	**30**	**35**
5	+ +	* +	+ +	* +	- +	- +
11	+ +	+ +	+ +	* +	- +	- +
22	+ -	+ -	+ -	+ -	- -	- -
25	+ -	+ -	+ -	+ -	- -	- -
30	+ -	+ -	+ -	+ -	- -	- -
35+	- *	- *	- *	- *	- *	- *

Table 2.2 Gravid *S. laticauda* collected from the Maurice River, NJ to provide juveniles for acute temperature-salinity challenges. Data are the number and total length of gravid females, brood size, and total length of juveniles for both trials.

	# Females	Female Total Length (mm)			Brood Size			Juvenile Total Length (mm)		
Trial		Mean	Min.	Max.	Mean	Min.	Max.	Mean	Min.	Max.
1	8	nd	nd	nd	45	12	70	2.2	1.6	2.8
2	8	12.1	11.1	13.1	52	29	60	2.1	1.8	2.6

Table 2.3 Results of summer 2006 presence-absence survey for *S. laticauda* along the New Jersey and Delaware coasts of Delaware Bay. Table indicates the survey site geographical coordinates, water temperature, and salinity for date(s) visited (month/day) and if isopods were present (+) or absent (-). Sites listed by latitude north to south in New Jersey then Delaware.

Location	Latitude	Longitude	Date	Isopod	Temp (ºC)	Salinity
New Jersey						
Pennsville	39º 38´ 27” N	75º 32´ 45” W	6/16	-	25.0	0
			8/18	-	29.0	0
Salam Boat Club	39º 34´ 46” N	75º 28´ 50” W	6/16	-	24.0	2
			8/18	-	27.5	1
Alloway Creek	39º 32´ 55” N	75º 24´ 48” W	6/16	-	23.5	2
			8/18	-	26.0	1
Hancocks Bridge	39º 32´ 05” N	75º 26´ 59” W	6/16	-	21.0	1
Greenwich Boatworks	39º 23´ 01” N	75º 21´ 01” W	6/16	+	22.0	10
			8/18	+	28.0	6
Fairton Marina	39º 22´ 51” N	75º 13´ 22” W	7/14	-	28.5	0
Hancock Harbor Marina	39º 22´ 45” N	75º 21´ 19” W	6/16	+	22.5	19
Iron Bridge Rd.	39º 22´ 53” N	75º 12´ 34” W	7/14	-	30.0	5
Spring Garden Marina	39º 19´ 32” N	75º 00´ 05” W	8/18	-	nd	0
Bay Point Marina	39º 17´ 52” N	75º 14´ 52” W	7/14	+	28.0	10
			8/18	+	27.0	17
Sundog Marina	39º 17´ 30” N	75º 11´ 50” W	6/23	+	28.0	17
			8/18	+	27.0	16
Maurice River Bridge	39º 17´ 14” N	74º 59´ 18” W	6/9	-	24.0	nd
Money Island Marina	39º 17´ 06” N	75º 13´ 50” W	6/23	+	28.0	18
			8/18	+	27.5	17
Money Island	39º 17´ 08” N	75º 13´ 48” W	8/18	+	27.0	17
Gandy's Beach Marina	39º 16´ 09” N	75º 13´ 37” W	6/23	-	27.0	16

Location	Latitude	Longitude	Date	Isopod	Temp (ºC)	Salinity
Dividing Creek	39º 15´ 60" N	75º 05´ 45" W	7/14	-	29.0	3
Penny Hill Boat Yard	39º 16´ 10" N	74º 59´ 00" W	8/04	-	33.0	0
Turkey Point	39º 14´ 45" N	75º 07´ 49" W	7/14	-	28.5	13
River Road Marina	39º 14´ 44" N	75º 00´ 15 W	8/04	+	33.0	0
Fortescue Ditch	39º 14´ 51" N	75º 10´ 17" W	6/23	-	29.5	16
Peek at Moon	39º 14´ 37" N	75º 01´ 01" W	8/04	+	30.0	5
Haskin Shellfish Lab	39º 14' 02" N	75º 01' 52" W	6/28 7/21 8/24	+ + +	24 29 27	10 12 18
Anchor Marina	39º 14´ 01" N	75º 00´ 40" W	8/04	+	31.0	5
Bayshore Project	39º 13' 58" N	75º 01' 57" W	6/3 6/25	+ +	23 24	15 11
Fish Tales Marina	39º 13´ 55" N	75º 00´ 50" W	7/21	+	29.0	8
Rigin Ditch	39º 13´ 06" N	74º 58´ 45" W	7/21	-	29.5	10
Popeyes Marina	39º 13´ 55" N	75º 00´ 55" W	8/04	+	31.5	6
East Point	39º 11´ 47" N	75º 01´ 41" W	7/21	+	29.0	12
Stipson Island	39º 11´ 17" N	74º 54´ 48" W	7/21	-	30.5	10
Goshen Landing	39º 08´ 27" N	74º 52´ 07" W	8/11	-	25.0	17
Smokeys Marina	39º 07´ 40" N	74º 53´ 18" W	6/30 8/11	+ +	27.0 25.0	21 17
Bayway Marina	39º 07´ 04" N	74º 52´ 09" W	6/30 8/11	- -	29.5 25.5	21 17
Reeds Beach	39º 06´ 57" N	74º 53´ 21" W	6/30	-	26.0	21
Kimble's Beach	39º 06´ 19" N	74º 53´ 42" W	6/30	-	28.0	23
Cooks Beach	39º 06´ 37" N	74º 53´ 34" W	8/11	-	25.0	17

Location	Latitude	Longitude	Date	Isopod	Temp (ºC)	Salinity
Pierces Pt Rd	39º 05´ 14” N	74º 54´ 13” W	8/11	-	27.0	20
Delaware						
Fort DuPont State Park	39º 34´ 42” N	75º 35´ 14” W	8/22	+	28.0	3
Delaware City Marina	39º 34´ 16” N	75º 35´ 25” W	8/22	+	28.0	2
C&D Canal	39º 33´ 31” N	75º 35´ 16” W	8/22	-	29.0	2
C&D Canal	39º 33´ 32” N	75º 34´ 20” W	8/22	-	29.0	2
Augustine Beach	39º 30´ 17” N	75º 34´ 48” W	8/22	-	30.5	2
Leipsic	39º 14´ 32” N	75º 30´ 57” W	8/22	-	29.0	20
Port Mahon	39º 11´ 40” N	75º 24´ 11” W	8/22	+	29.0	19
Bowers Beach	39º 03´ 29” N	75º 23´ 53” W	8/22	+	29.0	19

Table 2.4 Results of summer 2006 presence-absence survey for *S. laticauda* on New Jersey and Delaware oyster seed beds. Table indicates the survey site geographical coordinates, water temperature, and salinity for date(s) visited (month/day) and if isopods were present (+). Sites listed by latitude north to south.

Location[1]	**Latitude**	**Longitude**	**Date**	**Isopod**	**Temp**	**Salinity**
Arnolds	39º 23´ 00” N	75º 27´ 00” W	8/21	+	26.6	12
			9/18	+	23.5	10
			10/03	+	20.8	16
Middle	39º 19´ 55” N	75º 23´ 41” W	8/21	+	26.4	15
			9/18	+	23.2	13
Cohansey	39º 19´ 30” N	75º 22´ 18” W	7/25	+	26.6	12
			8/21	+	26.3	16
			10/03	+	20.6	11
Ship John	39º 18´ 18” N	75º 22´ 42” W	8/07	+	24.8	9
			8/21	+	26.4	11
Shell Rock	39º 17´ 30” N	75º 20´ 30” W	7/25	+	26.3	12
			8/21	+	25.9	17
Nantuxent Point	39º 16´ 13” N	75º 15´ 00” W	7/25	+	26.4	12
			8/07	+	27.0	19
			8/21	+	26.1	18
			9/07	+	22.3	19
			9/18	+	22.5	18
			10/03	+	19.5	15
Over the Bar	39º 15´ 32” N	75º 22´ 47” W	8/07	+	26.2	19
			8/18	+	25.7	27
			9/07	+	22.5	16
Bennies	39º 15´ 12” N	75º 18´ 00” W	9/07	+	23.1	18
New Beds	39º 15´ 06” N	75º 15´ 06” W	9/07	+	22.9	18
			9/18	+	22.6	18
Lower Middle	39º 13´ 55” N	75º 21´ 32” W	8/07	+	26.1	19
			8/18	+	25.8	18
			9/07	+	22.5	17
Silver	39º 13´ 11” N	75º 22´ 57” W	8/07	+	27.5	16
			8/18	+	25.8	19
			9/07	+	23.2	18
Egg Island Bed	39º 12´ 42” N	75º 11´ 30” W	8/07	+	26.2	22
			8/21	+	25.8	20

Location[1]	Latitude	Longitude	Date	Isopod	Temp	Salinity
Ridge	39º 12´ 40” N	75º 21´ 30” W	8/07	+	nd	nd
			8/18	+	25.4	20
			9/07	+	22.3	20
554D	39º 11´ 00” N	75º 11´ 18” W	9/07	+	22.1	24
			9/18	+	22.5	22
99C	39º 10´ 6” N	75º 05´ 02” W	8/07	+	27.5	20
			8/21	+	26.1	22
			9/07	+	22.0	21
			9/18	+	22.3	22
			10/03	+	19.2	19

[1] Traditional name of oyster seed bed

Table 2.5 Results of summer 2006 presence-absence survey for *S. laticauda* along the Atlantic coast of New Jersey. Table indicates the survey site geographical coordinates, water temperature, and salinity for date(s) visited (month/day) and if isopods were present (+) or absent (-). Sites listed by latitude north to south.

Location	**Latitude**	**Longitude**	**Date**	**Isopod**	**Temp (ºC)**	**Salinity**
Liberty State Park	40º 41´ 41” N	74º 03´ 40” W	7/29	-	29.0	10
Veterans Memorial Park	40º 40´ 18” N	74º 07´ 28” W	7/29	-	29.0	11
Bayonne City Park	40º 39´ 46” N	74º 07´ 59” W	7/29	-	29.0	11
Red Bank Marine Park	40º 21´ 16” N	74º 03´ 52” W	7/29	-	29.0	21
Berkeley Island County Park	39º 52´ 21” N	74º 08´ 12” W	7/28	-	27.5	19
Townsends Marina	39º 49´ 52” N	74 º11´ 13”W	7/28	-	29.0	21
Absecon Bridge	39º 25´ 23” N	74º 30´ 26” W	7/07	-	26.0	0
Absecon Boat Ramp	39º 25´ 34” N	74º 29´ 11” W	7/28 8/25	- -	30.5 27.0	19 25
Bayside Boat and Tackle	39º 23´ 43” N	74º 23´ 29” W	7/28	-	27.0	30
Sea Village Marina	39º 21´ 12” N	74º 32´ 16” W	7/28	-	28.0	27
Beeselys Point Boat Ramp	39º 17´ 16” N	74º 37´ 37” W	7/07 8/04	- -	27.0 33.0	15 18
Yank Marina	39º 17´ 41” N	74º 44´ 57” W	8/04	-	33.0	0
Avalon Bridge	39º 06´ 35” N	74º 44´ 33” W	7/07 8/25	- -	23.5 26.5	32 32
Springer Mill Rd.	39º 05´ 00” N	74º 53 03” W	6/30	-	29.5	11
Wetlands Institute	39º 03´ 27” N	74º 46´ 32” W	7/07 8/25	- -	25.0 24.5	32 34

Location	Latitude	Longitude	Date	Isopod	Temp (ºC)	Salinity
Stone Harbor Marina	39º 03´ 31” N	74º 45´ 59” W	7/07 8/25	- -	24.0 26.0	31 32
Pier 47 Marina	38º 59´ 51” N	74º 51´ 06” W	8/11	-	25.5	32
Lighthouse Marina	38º 59´ 22” N	74º 50´ 12” W	8/11	-	25.0	31
B and E Marina	38º 59´ 22” N	74º 49´ 60” W	8/11	-	26.0	32
Miss Chris Fishing Center	38º 57´ 01” N	74º 54´ 37” W	8/11	-	26.0	30
South Jersey Marina	38º 57´ 08” N	74º 54´ 21” W	8/11	-	25.0	31
Rutgers Extension	38º 56´ 44” N	74º 53´ 54” W	6/09	-	24.0	30

Table 2.6 Results of September 16, 2006 presence-absence survey for *S. laticauda* along the Atlantic Intracoastal Waterway. Table indicates survey site geographical coordinates, water temperature, salinity, and if isopods were present (+) or absent (-). Sites were located at ICW channel markers and listed by latitude north to south.

Location[1]	Latitude	Longitude	Isopod	Temp (ºC)	Salinity
R 128	39º 30´ 12” N	74º 20´ 36” W	-	20.5	31
R 138	39º 29´ 53” N	74º 22´ 32” W	-	20.0	26
R 156	39º 27´ 35” N	74º 23´ 37” W	-	20.5	25
R 159	39º 27´ 03” N	74º 23´ 32” W	-	20.0	26
G 171	39º 25´ 59” N	74º 24´ 54” W	-	20.5	27
G 175	39º 25´ 10” N	74º 25´ 35” W	-	20.0	28
R 178	39º 25´ 10” N	74º 25´ 35” W	-	20.0	30
R 184	39º 23´ 22” N	74º 26´ 23” W	-	20.5	32
R 187	39º 23´ 18” N	74º 26´ 54” W	-	20.5	32
G 195	39º 22´ 25” N	74º 27´ 34” W	-	21.0	31
R 202	39º 22´ 05” N	74º 26´ 45” W	-	21.0	31
G 213	39º 21´ 12” N	74º 29´ 34” W	-	22.0	32
R 222	39º 20´ 33” N	74º 30´ 41” W	-	21.5	31
R 228	39º 19´ 33” N	74º 31´ 18” W	-	21.0	33
R 258	39º 16´ 42” N	74º 35´ 24” W	-	21.0	33
R 266	39º 16’ 17” N	74º 37’ 16” W	-	22.0	28
R 285	39º 14´ 50” N	74º 37´ 39” W	-	22.5	27
G 295	39º 14´ 36” N	74º 38´ 18” W	-	22.0	30
R 305	39º 13´ 35” N	74º 39´ 20” W	-	22.0	32
R 320	39º 12´ 18” N	74º 40´ 14” W	-	22.0	32
G 335	39º 11´ 43” N	74º 41´ 34” W	-	21.5	33
R 342	39º 10´ 56” N	74º 41´ 59” W	-	21.5	32
R 350	39º 10´ 03” N	74º 42´ 00” W	-	22.0	32
R 361	39º 08´ 55” N	74º 42´ 23” W	-	21.5	32

Location[1]	Latitude	Longitude	Isopod	Temp (ºC)	Salinity
R 374	39º 06´ 56” N	74º 43´ 32” W	-	21	32
G 385	39º 05´ 44” N	74º 45´ 56” W	-	21.5	32
R 410	39º 03´ 46” N	74º 45´ 26” W	-	21.5	32
R 430	39º 02´ 21” N	74º 47´ 40” W	-	21.5	35
R 446	39º 00´ 36” N	74º 49´ 03” W	-	21.5	32
G 463	38º 59´ 36” N	74º 50´ 02” W	-	22	32
G 469	38º 59´ 03” N	74º 50´ 42” W	-	21.5	34
G 473	38º 58´ 15” N	74º 51´ 48” W	-	21.5	33

[1] US Coast Guard Channel Marker

Table 2.7 Results of August 19, 2006 presence-absence survey for *S. laticauda* along the Atlantic coast of Delaware. Table indicates survey site geographical coordinates, water temperature, salinity, and if isopods were present (+) or absent (-). Sites listed by latitude north to south.

Location	**Latitude**	**Longitude**	**Isopod**	**Temp (ºC)**	**Salinity**
U. Del College M & E Sciences	38º 47’ 15” N	75º 09’ 41” W	-	28	30
Lewes and Rehoboth Canal	38º 47´ 24” N	75º 09´ 47” W	-	25.5	30
Thompson’s Inlet	38º 41´ 54” N	75º 06´ 35” W	-	27	29
Indian Bay	38º 34´ 50” N	75º 05´ 12” W	-	27	29

Table 2.8 Combined results of two adult *S. laticauda* temperature-salinity challenges. Values indicate the mean proportion of isopods scored (± 1 SE) as live following 48 h acute exposure.

	Salinity					
Temp (°C)	**0**	**5**	**15**	**25**	**30**	**35**
5	0.00 (± 0.0)	0.94 (± 0.06)	0.94 (± 0.04)	1.0 (± 0.0)	1.00 (± 0.0)	1.00 (± 0.0)
11	0.00 (± 0.0)	0.86 (± 0.07)	0.81 (± 0.07)	0.89 (± 0.06)	0.89 (± 0.06)	1.00 (± 0.0)
21	0.0 (± 0.0)	0.94 (± 0.06)	0.89 (± 0.06)	1.0 (± 0.0)	nd	nd
25	0.06 (± 0.06)	0.83 (± 0.10)	0.89 (± 0.06)	0.89 (± 0.06)	nd	nd
30	0.00 (± 0.0)	0.00 (± 0.00)	0.83 (± 0.1)	0.80 (± 0.12)	nd	nd

Table 2.9 Results of juvenile *S. laticauda* acute 24 h temperature-salinity challenge (Trial 1.) and the 24 h recovery period. Values indicate the mean proportion of juvenile *S. laticauda* scored as alive. Bracketed numbers are the mean proportion of isopods scored alive [if different than the initial 24 h score] following 24 h recovery period.

	Salinity					
Temp (ºC)	**0**	**5**	**10**	**25**	**30**	**35**
4	0.00	0.00	0.00 [0.70]	1.00 [0.90]	0.30 [0.60]	0.20 [0.10]
10	0.00	0.00	0.70 [0.40]	0.90	0.80 [0.50]	1.00 [0.70]
25	0.00 [0.10]	0.10 [0.00]	0.30	0.90 [0.70]	0.70	0.70
33	0.00	0.00	0.00	0.50	0.20 [0.10]	0.10 [0.00]
37	0.00	0.00	0.00	0.00	0.00	0.00

Table 2.10 Results of juvenile *S. laticauda* acute 24 h temperature-salinity challenge (Trial 2.). Values indicate the mean proportion of juvenile *S. laticauda* scored as alive.

	Salinity					
Temp (°C)	**0**	**5**	**10**	**20**	**30**	**35**
4	0.00	0.00	0.00	0.10	0.00	0.00
10	0.00	0.10	0.80	1.00	0.90	0.30
25	0.10	0.10	1.00	0.90	0.90	0.10
30	0.00	0.00	0.00	0.30	0.00	0.00
37	0.00	0.00	0.00	0.00	0.00	0.00

Table 2.11 ANOVA table indicating that the number of *S. laticauda* associated with fouled and clean cages in the Maurice River, NJ.

Source	Sum-of-Squares	df	Mean-Square	F-ratio	P
Treatment	16700.017	1	16700.017	6.949	0.012
Date	53993.017	9	5999.224	2.496	0.023
Treatment x Date	26186.483	9	2909.609	1.211	0.316
Error	96127.333	40	2403.183		

Table 2.12 Mean abundances of fauna collected from cleaned and fouled cages. Fauna include the non-indigenous isopod (*Synidotea laticauda*), mud crab (*Panopeus* sp.), grass shrimp (*Palaemon* sp.), amphipod (*Amphipoda*), oyster toadfish (*Opsanus tau*)**,** naked gobi (*Gobisoma bosc*), and blue crab (*Callinectes sapidus*).

Date	Isopod	Mud crab	Shrimp	Amphipod	Toadfish	Gobi	Blue crab
Cleaned							
6/14	62.3	0.0	2.0	7.0	0.0	0.0	0.0
6/21	92.0	0.7	1.0	1.0	0.0	0.0	0.0
6/28	43.7	2.7	1.7	0.0	0.0	0.0	0.0
7/5	76.7	2.7	1.3	0.0	1.3	0.0	0.0
7/12	80.7	12.7	0.7	1.7	0.7	0.0	0.0
7/19	62.7	26.0	1.3	0.0	0.0	0.0	0.0
7/26	32.0	12.3	1.0	0.3	0.0	0.0	0.0
8/2	77.0	10.3	0.7	1.0	0.3	0.7	0.7
8/9	39.0	8.0	1.7	1.3	0.0	0.3	6.3
8/16	57.7	4.3	6.3	0.0	0.3	0.0	5.0
Mean	**62.4**	**8.0**	**1.8**	**1.2**	**0.3**	**0.1**	**1.2**
Fouled							
6/14	21.7	1.0	2.7	18.7	0.0	0.0	0.0
6/21	123.7	4.7	6.0	4.7	0.0	0.0	0.0
6/28	97.3	4.0	1.0	0.0	0.0	0.0	0.0
7/5	158.7	6.0	1.7	0.0	1.0	0.0	0.0
7/12	187.3	18.7	1.7	3.3	0.0	0.3	0.0
7/19	55.7	63.3	1.0	0.0	0.3	0.7	0.0
7/26	75.0	12.0	0.7	0.0	0.3	0.0	0.0
8/2	74.7	22. 3	2.7	0.0	0.0	0.0	0.0
8/9	52.0	7.3	0.7	0.0	0.0	0.3	9.0
8/16	111.1	9.3	3.3	0.3	0.3	0.3	2.3
Mean	**95.7**	**14.0**	**2.2**	**2.7**	**0.2**	**0.2**	**1.1**

Table 2.13 ANOVA table indicating a significant difference in length (mm) of *S. laticauda* recruiting weekly to fouled and clean cages in the Maurice River, NJ.

Source	Sum-of-Squares	df	Mean-Square	F-ratio	P
Treatment	615.865	1	68.429	10.750	0.000
Date	34.033	9	34.033	5.346	0.021
Treatment x Date	64.766	9	7.196	1.130	0.337
Error	10185.051	160	6.366		

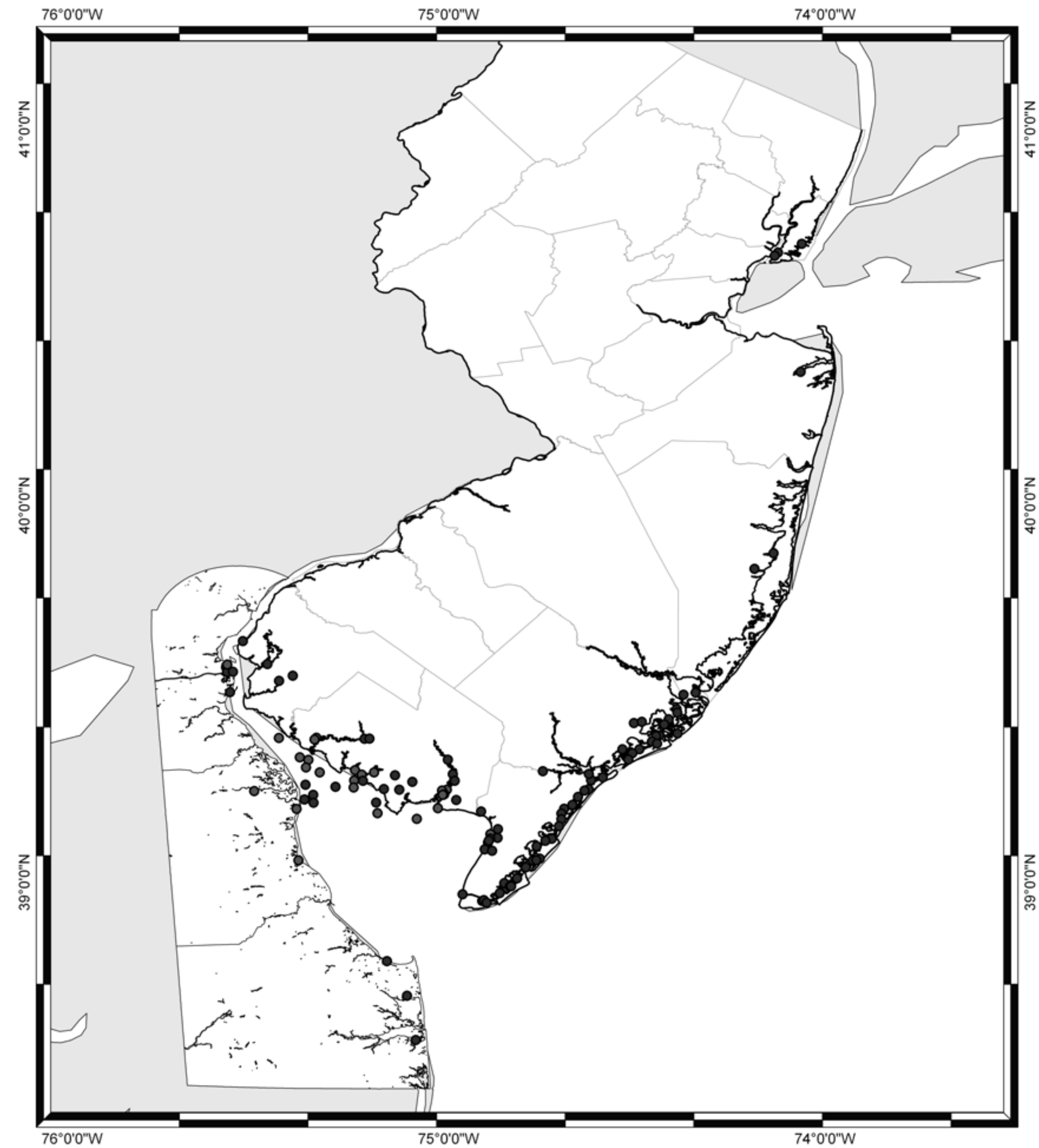

Figure 2.1 Sampling sites for the presence-absence survey conducted in Delaware Bay and adjacent waters for *S. laticauda* during the summer of 2006.

Figure 2.2 Wire-mesh cage deployed in the Maurice River, NJ to assess the affinity of *S. laticauda* for biologically fouled structures.

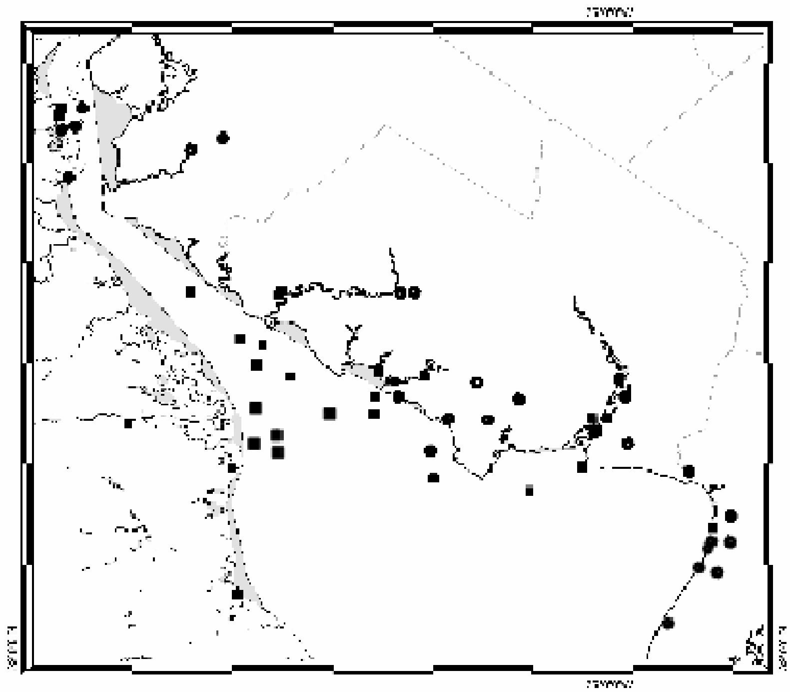

Figure 2.3 Presence-absence survey sites in Delaware Bay were *S. laticauda* were observed (■) and not observed (●).

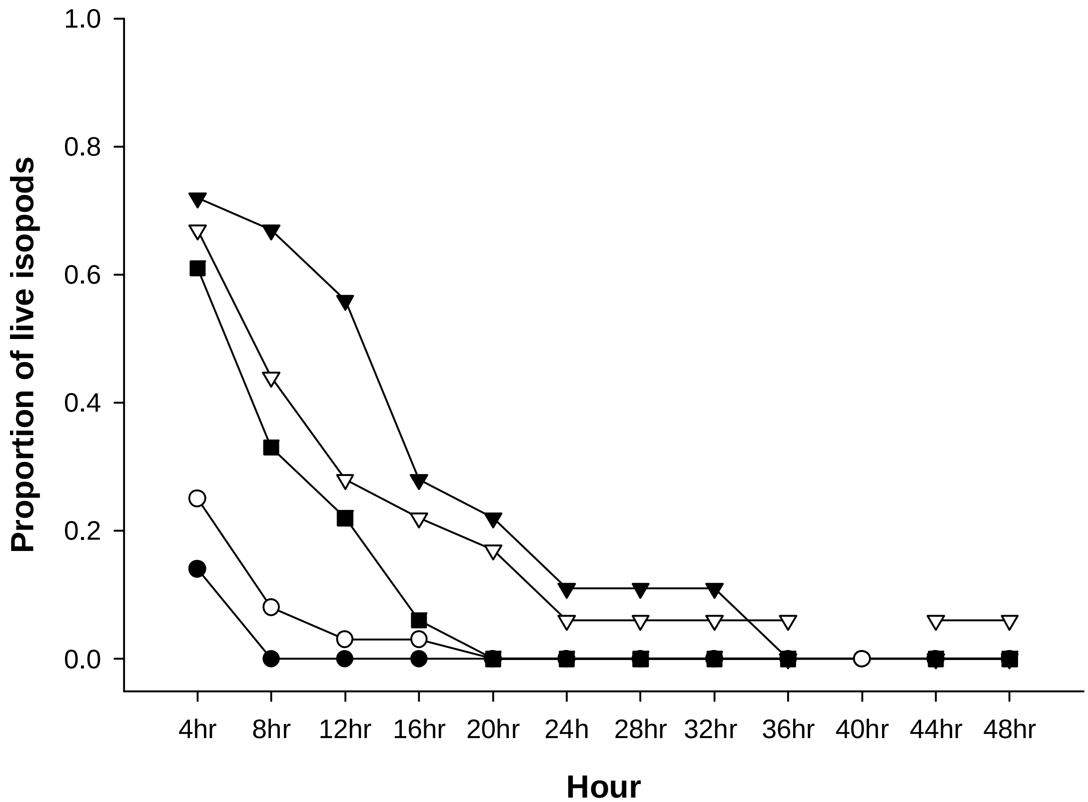

Figure 2.4 Survival of adult *S. laticauda* temperature-salinity trials at various temperatures in freshwater (salinity = 0). Temperature treatments were 5 ºC (filled circle), 11 ºC (open circle), 21 ºC (upside down closed triangle), 25 ºC (open triangle), and 30 ºC (closed square).

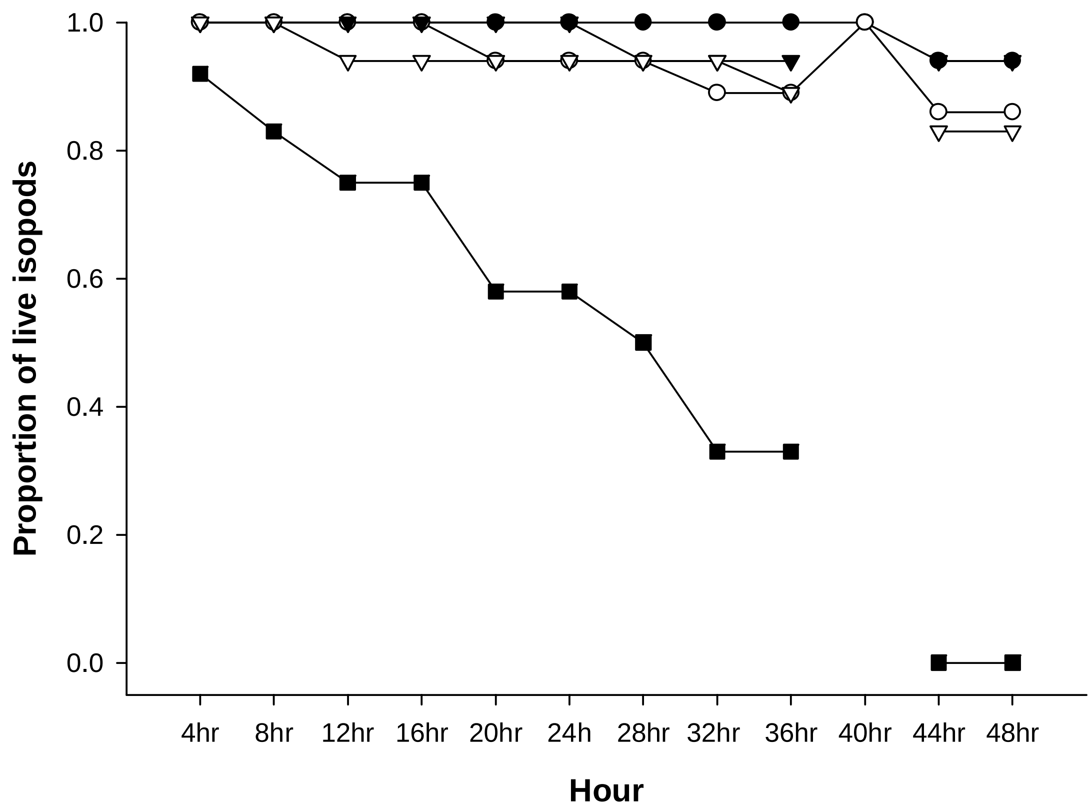

Figure 2.5 Survival of adult *S. laticauda* at various temperatures at salinity of 5. Temperature treatments were 5 ºC (closed circle), 11 ºC (open circle), 21 ºC (upside down triangle), 25 ºC (open triangle), and 30 ºC (closed square).

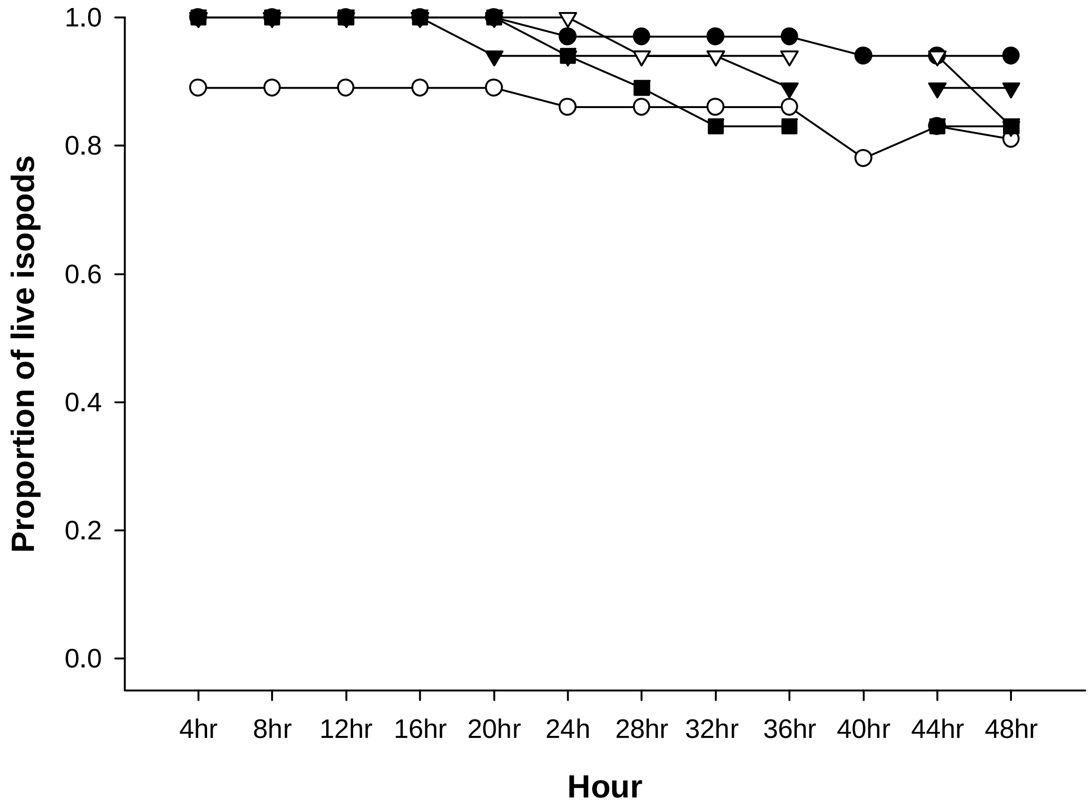

Figure 2.6 Survival of adult *S. laticauda* at various temperatures at salinity of 15. Temperature treatments are 5 ºC (closed circle), 11 ºC (open circle), 21 ºC (upside down closed triangle), 25 ºC (open triangle), and 30 ºC (closed square).

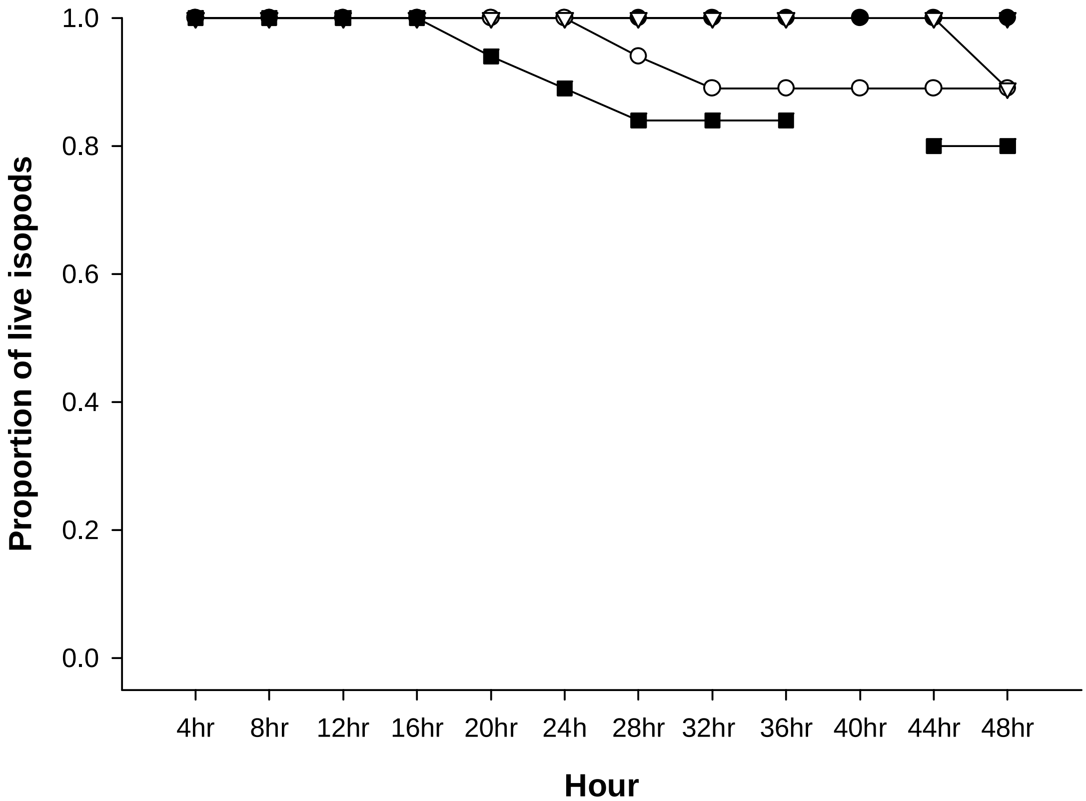

Figure 2.7 Survival of adult *S. laticauda* at various temperatures at salinity of 25. Temperature treatments are 5 ºC (closed circle), 11 ºC (open circle), 21 ºC (upside down triangle), 25 ºC (open triangle), and 30 ºC (closed square).

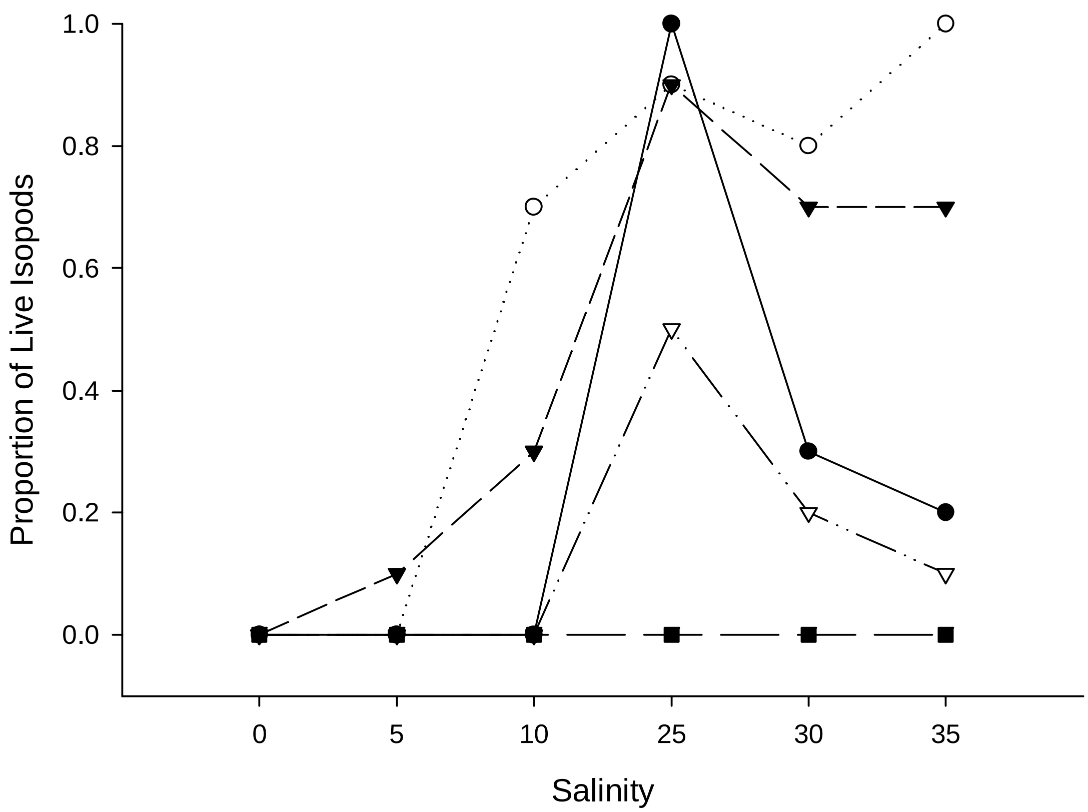

Figure 2.8 Mean survival of juvenile *S. laticauda* in 24 h acute temperature-salinity challenge (Trial 1) Treatments are 4 ºC (closed circle), 10 ºC (open circle), 25 ºC (upside down closed triangle), 33 ºC (open triangle), and 37 ºC (closed square)

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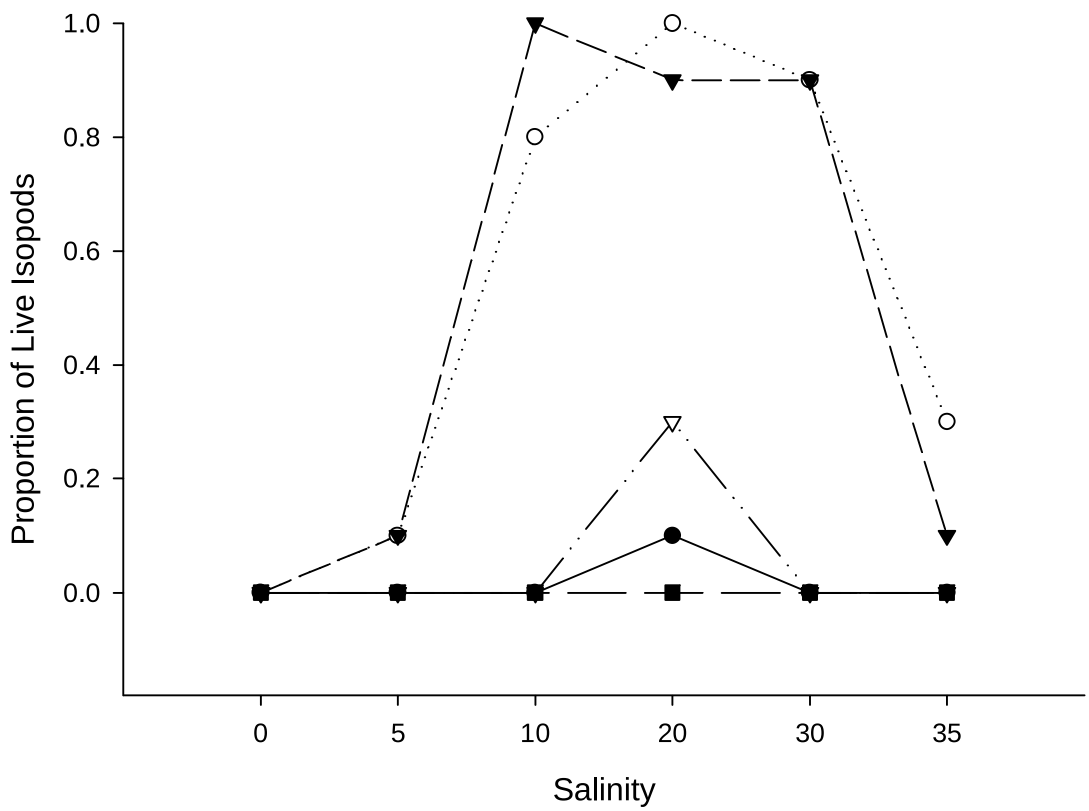

Figure 2.9 Mean survival of juvenile *S. laticauda* in 24 h acute temperature-salinity challenge (Trial 2). Treatments are 4 ºC (closed circle), 10 ºC (open circle), 20 ºC (upside down closed triangle), 33 ºC (open triangle), and 37 ºC (closed square).

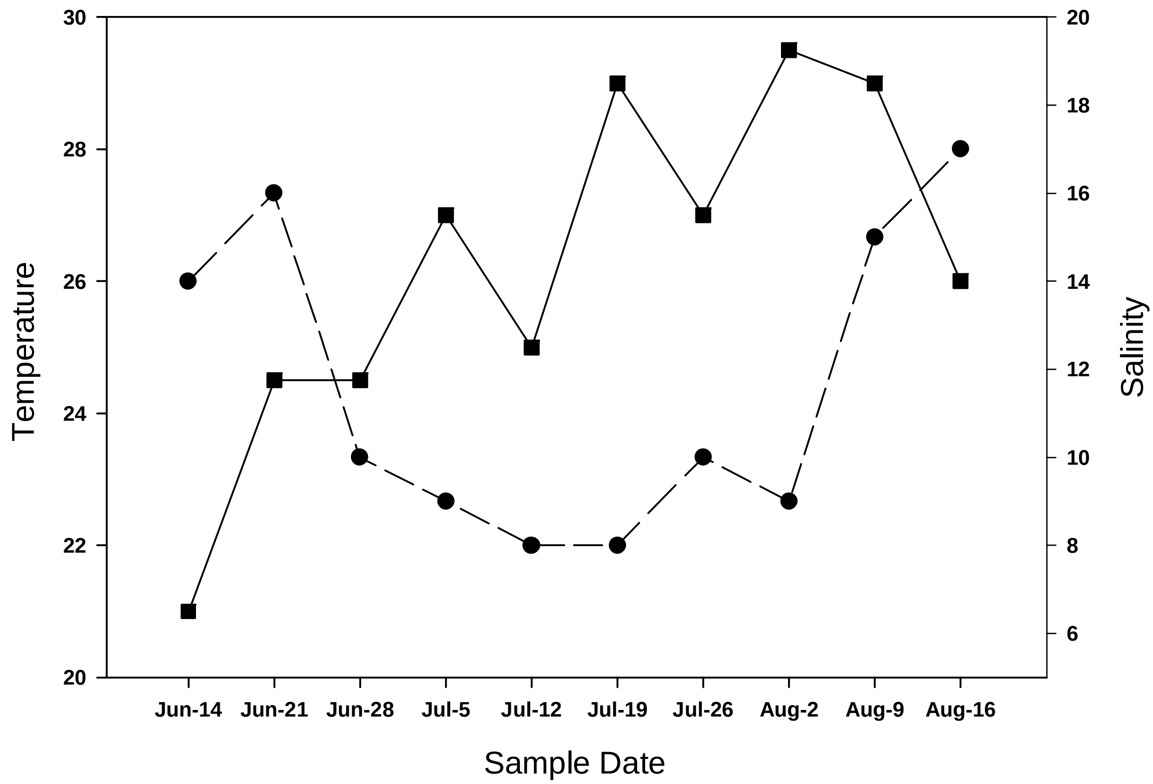

Figure 2.10 Temperature and salinity of the Maurice River, NJ, during retrieval of bio-fouled and cleaned cages. Temperature (ºC) ■, Salinity ●.

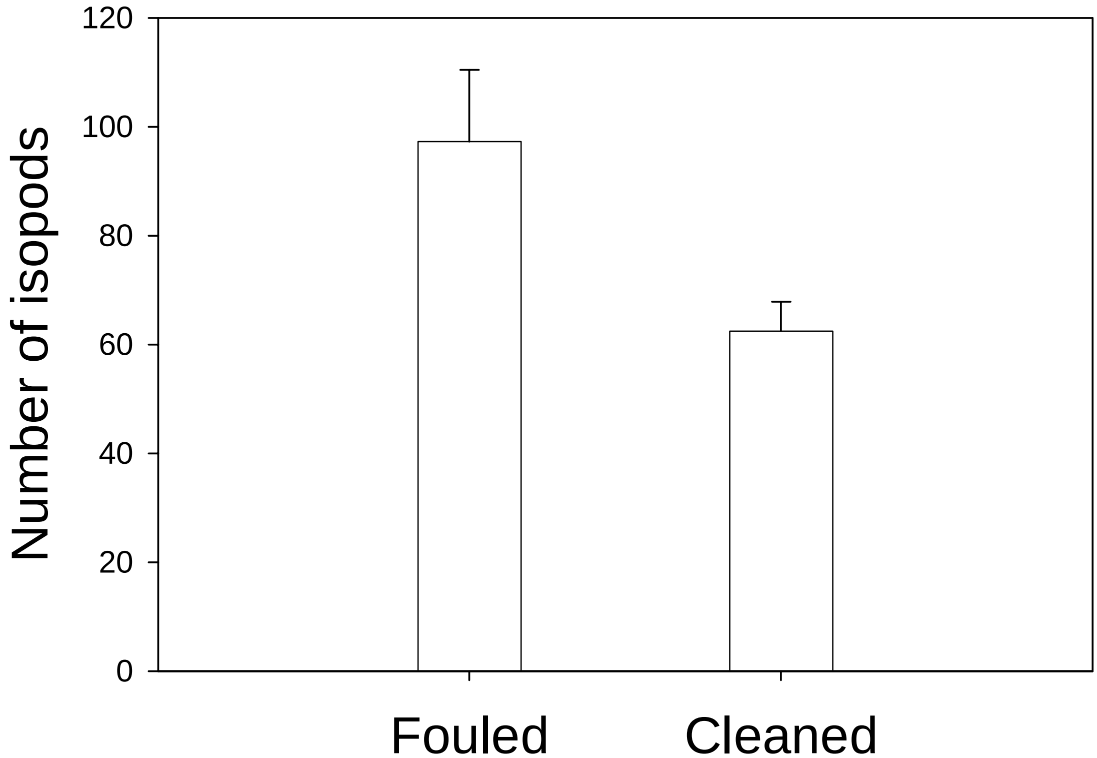

Figure 2.11 Mean abundance (± 1 SE) of *S. laticauda* on cages in the Maurice River, NJ

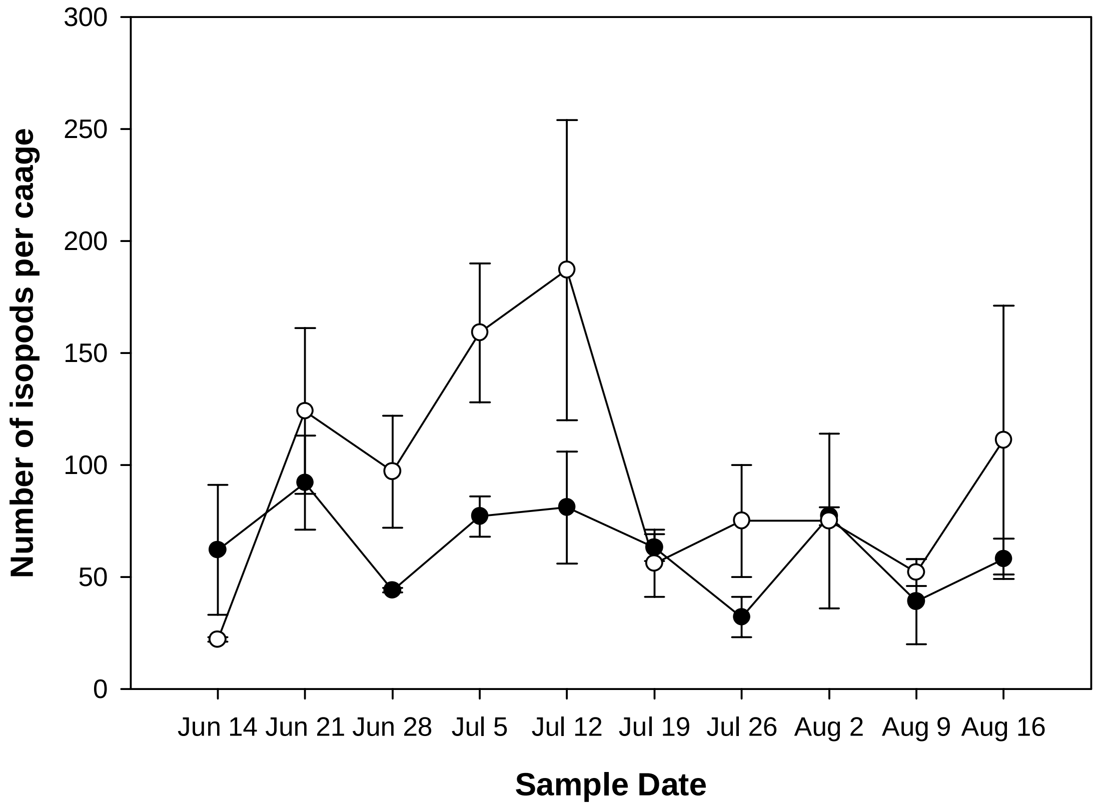

Figure 2.12 Mean abundance (± 1 SE) of *S. laticauda* on cages in the Maurice River, NJ. Biological fouling accumulated on one set of cages (○) while the other set was cleaned weekly (●).

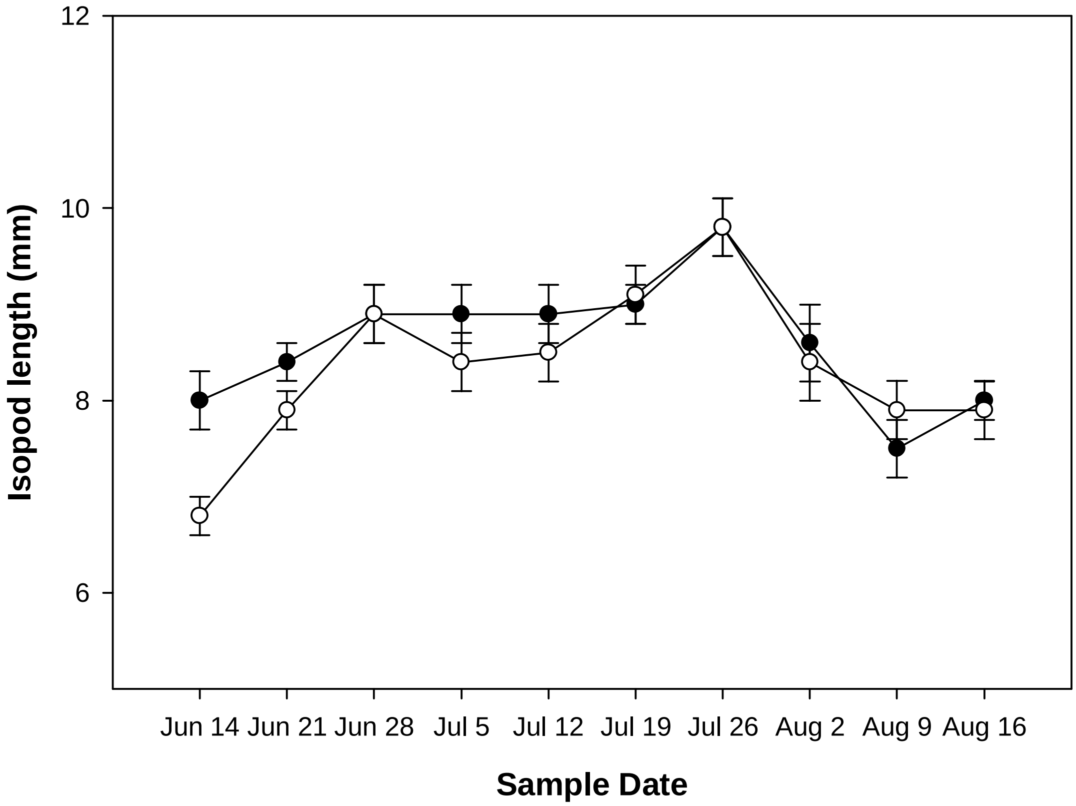

Figure 2.13 Weekly mean length (± 1 SE) of *S. laticauda* on cages in Maurice River, NJ. Biological fouling accumulated on one set of cages (○) while the other set was cleaned weekly (●).

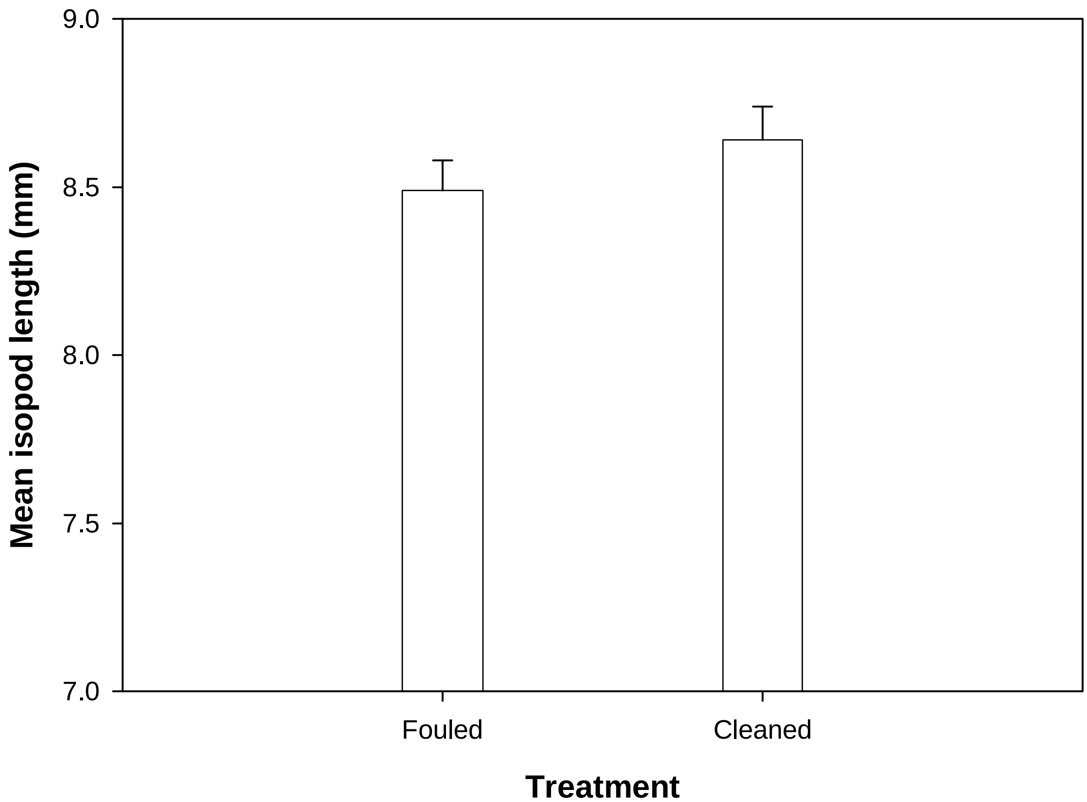

Figure 2.14 Mean lengths (± 1 SE) of *S. laticauda* recruiting weekly to fouled and cleaned cages in the Maurice River, NJ.

3.0 TROPHIC DYNAMICS OF *S. LATICAUDA* IN DELAWARE BAY

3.1 INTRODUCTION

Synidotea laticauda is a recent arrival to Delaware Bay (Bushek and Boyd 2006). To persist, *S. laticauda* must establish an ecological niche within the existing biotic and abiotic communities of the bay. Two important niche parameters include the availability of food resources and the impact of potential predators. Both of these parameters are particularly important in the successful establishment of non-indigenous species. Defining niche characteristics of *S. laticauda* within Delaware Bay will help determine the potential effects of its introduction on the local and neighboring ecosystems.

The food resources available to a non-indigenous species depend on the foraging strategies of that species as well as the community structure of the recipient region in which it has arrived. If the non-indigenous species is a specialist and only exploits particular food resources, such as a single species of plant, and that resource is absent in the recipient range then the invasion will fail unless that species can adapt to alternative resources. Alternatively, generalists with broad diets may not find their preferred food resources in a recipient region but would likely persist by consuming native food resources without the need to adapt.

Non-indigenous species are frequently separated from native predators as they move from a donor to a recipient region. In the absence of predation and other natural population controls, such as pathogens and parasites, non-indigenous species may experience rapid population growth. However, they may encounter naïve predators in the recipient regions with which they have no previous experience (ANSTF 1994). Naïve predators may have little impact on population growth or they may exert enough predation pressure to suppress rapid growth, allowing only a minimal population to persist. Alternatively, naïve predators may overwhelm non-indigenous species, preying on a sufficient number of individuals to cause the invasion to fail.

This study addresses trophic relationships between *S. laticauda* and the biota of Delaware Bay. Multi-generational recruitment of this isopod has been documented over several years in Delaware Bay indicating the successful establishment of a local population (Bushek and Boyd 2006). Therefore, it is hypothesized that *S. laticauda* is exploiting at least one local food resource. *In vitro* feeding trials were conducted with select local biota to identify potential food resources for *S. laticauda*. It is also hypothesized that native predatory fish species within Delaware Bay are incorporating *S. laticauda* into their diets. Hence, the gut contents of several local fish species were examined to determine if *S. laticauda* was being consumed.

3.2 MATERIAL AND METHODS

3.2.1 Feeding Trial

Single-choice *in vitro* feeding trials were conducted at HSRL from June to August 2006, to identify potential food resources capable of exploitation by *S. laticauda* in Delaware Bay. Adult isopods were collected from plastic mesh oyster bags, maintained in the Maurice River (39º 13’ 58” N, 75º 01’ 57” W) by the BDP, and acclimated without food in a 10-l aerated aquarium for 72 h. The aquarium contained room temperature (18-23 ºC) artificial seawater (ASW) prepared by mixing 250 g of Instant Ocean® in 10-l of de-ionized water and held in plastic carboys for use as needed.

Eleven commonly occurring species, from multiple taxa, were collected from around Delaware Bay and a twelfth was collected from the Atlantic coast of New Jersey (Table 3.1). These prey items consisted of live motile and sessile fauna and flora, and the carrion of dead organisms. Prey items were divided into equivalent sized portions and distributed among three Carolina culture dishes®, each containing 200-ml of ASW. For each prey item, eight isopods were removed from the aquarium and distributed to two of the three dishes. The third dish was maintained as a control to account for any degradation of prey independent of the isopods. Qualitative observations were recorded periodically over 48 h and included the quantity and condition of the remaining prey. Multiple replicate feeding trials were completed for each prey item.

3.2.2 Gut Content Analyses

Gut content Analyses assessed whether trophic interactions exist between *S. laticauda* and eight species of fish in Delaware Bay. Fish were collected from two inshore sites and at multiple open water locations in the lower Delaware Bay during the summer of 2006. A multi-species trap, with 3.5-cm mesh and 15-cm circular openings at opposite ends, was used to collect fish inshore near the mouths of two tributaries. The trap was weighted with a brick and baited with Atlantic menhaden (*Brevoortia tryannus*), white perch (*Morone americana*), or white catfish (*Ameiurus catus*), depending on availability. It was secured to the dock with rope and lowered onto or near the bottom of the river for approximately 24 h. The trap was deployed repeatedly in the Maurice River (39º 14” 02’ N 75º 01” 52’ W) between June 1 and August 2, 2006 and in the Nantuxent River (39º 17’ 04” N 75º 13” 52’ W) between August 4 and 20, 2006. *Synidotea* *laticauda* was abundant at both sites during all deployments. Deployment and retrieval of the trap was in the morning for the Maurice River and in the early afternoon for the Nantuxent River. Inshore fish collection ceased following a strong tidal cycle in the Nantuxent River that damaged the trap.

Recreational fishermen and New Jersey state biologists provided fish from the open waters of Delaware Bay. The *Miss Fortescue*, a party boat operating out of Fortescue, NJ, provided filleted fish carcasses following multiple fishing trips throughout the summer of 2006. Participants in the weakfish tournament held August 19 2006, at Smokey's Marina in Cape May Courthouse, NJ, also provided filleted fish carcasses. Finally, NJDEP biologists contributed juvenile fish from an inshore trawl survey conducted on August 16, 2006.

Wet weight and fork length measurements for each fish were recorded when possible. Fish stomachs were removed with a scalpel and scissors and stored in plastic bags in a -25 °C freezer at HSRL. Fish caught inshore with the multi-species trap were anesthetized in ice water and their spinal cords severed. A dorsal-ventral incision between the operculum and pectoral fins severed the esophagus and a second incision between the anal vent and the head exposed the stomach for removal. Fish provided by recreational fishermen had been filleted beforehand by the fishermen allowing easy removal of the stomach but prevented wet weight measurements. For fish caught in the multi-species trap, the time between collection and gut removal was approximately one hour. The time between capture and gut removal for fish provided by local fishermen and the NJDEP is unknown.

The stomach contents were examined in January 2007. Stomachs were thawed overnight at room temperature and examined individually under a dissecting microscope for evidence of *S. laticauda.* The distinctive concave shape of the *S. laticauda* telson was used to positively identify their presence. The frequency of *S. laticauda* in the stomachs of each fish species are reported using the formula $F_i = 100\ n_i /n$ where n is the number of fish stomachs containing food and n_i is the number of stomachs with *S. laticauda* present (Lima-Junior and Goitein 2001).

3.3 RESULTS

3.3.1 Feeding Trial

Synidotea laticauda consumed nine of the twelve species presented during 48-h, single-choice, *in vitro* feeding trials (Table 3.1). Motile species consumed by *S. laticauda* included nereid worms, which were grasped and held tightly against the isopod's body. Complete consumption of the worms occurred within a couple of hours. *Synidotea laticauda* also preyed on zooplankton and conspecific juveniles. They appeared to use their front pereopods to capture prey items swimming by. The carrion of eastern oysters (*Crassostrea virginica*), blue crabs (*Callinectes sapidus*), and conspecific isopods was also consumed by *S. laticauda*. Isopods crawled over carrion and removed large pieces of tissue. Isopods quickly consumed *Ulva* sp. but took longer to eat the *Spartina alterniflora* which floated on the water surface. Isopods clung to the *S. alterniflora* with their pereopods while consuming the edges of leaves. *Synidotea laticauda* were not observed consuming *Fucus* sp., that was collected from the Atlantic coast of New Jersey. Also not consumed were sea anemones and an unidentified fungus growing on oyster shells.

3.3.2 Gut Content Analyses

The gut contents of 183 fish collected from Delaware Bay during the summer of 2006 were examined for *S. laticauda*. Four species of fish were caught in tributaries with the multi-species trap between June and August 2006 (Table 3.2). White perch (*Morone americana*) and oyster toadfish (*Opsanus tau*) were caught in both the Nantuxent and Maurice Rivers, while white catfish (*Ameiurus catus*) and American eel (*Anguilla rostrata*) were caught only in the Maurice River. Four other fish species (Table 3.2) were caught in the open waters of Delaware Bay between July and August 2006 by recreational fishermen and state biologists. All fish were large enough to easily consume *S. laticuada*. Many fish caught by fishermen had been filleted and could not be properly weighed (Table 3.3). Sixteen fish from five taxa contained one or two *S. laticauda* in their guts (Table 3.4). With the exception of a single Atlantic croaker (*Micropogonias undulatus*), fish that consumed *S. laticauda* were collected from the Maurice or Nantuxent Rivers and not the open waters of the bay.

White perch were the dominant fish collected in tributaries. *Synidotea laticauda* were identified in 37% of the guts containing food (Table 3.4). Other prey items noted in the stomachs of perch included juvenile horseshoe crabs, fish scales, shrimp, and crab fragments. The oyster toadfish was the second most abundant species collected inshore. Small fish, worms, and crab fragments were found in the guts of many individuals, while *S. laticauda* were identified in only two toadfish caught in the Maurice River. *Synidotea* *laticauda* were also identified in the guts of three of the nine white catfish caught in the Maurice River. With only two individuals caught from the Maurice River, the American eel (*Anguilla rostrata*) was the least abundant fish collected from the tributaries. One eel contained a single *S. laticauda*, while the gut of the second was empty.

Although Atlantic croaker was the most abundant fish sampled, only a single fish, provided by the NJDEP, was found with an isopod in its gut (Table 3.4). Other Atlantic croaker stomachs contained fragments of grass shrimp and crab. *Synidotea laticauda* were not identified in the guts of the other three species caught in Delaware Bay. The guts of weakfish (*Cynoscion regalis*) contained crab fragments, fish, and sea stars. Summer flounder (*Paralicthys dentatus*) stomachs were empty, and the three juvenile black sea bass (*Centropristis striata*) caught by the NJDEP contained only remnants of crab.

3.4 DISCUSSION

Several trophic interactions between *S. laticauda* and the biota of Delaware Bay were identified in this study. Single-choice *in vitro* feeding trials identified nine different fauna and flora species that were readily consumed by *S. laticauda*, establishing it as an omnivore capable of exploiting multiple food resources within the Bay. Gut content analyses of fish collected from the Nantuxent and Maurice Rivers indicate that at least four species of fish consume *S. laticauda*, although it did not appear to be an important component of their diet.

Non-indigenous species with broad diets are far more likely to succeed in a recipient region than species capable of exploiting limited food resources. Although various foraging strategies exist among Isopoda, most isopods are either scavengers or omnivores with broad diets (Barnes 1980). Little information exists on the diet of *S. laticauda*, although, Menzies and Miller (1972) speculate that their diet may include bryozoans and a hydroid which occur in its native San Francisco Bay habitat. In Delaware Bay, *S. laticauda* are frequently associated with anthropogenic habitats containing *Ulva* sp. and branching bryozoans. Both were quickly consumed during *in vitro* feeding trials. *Spartina alterniflora* was also readily consumed in *in vitro* feeding trials. Although not specifically identified as isopod habitat by the presence-absence survey described in the previous chapter, *S. alterniflora* was included as a potential food resource because *S. laticauda* has been found among floating plant debris, including *S. alterniflora*, at numerous Delaware Bay marinas. *Synidotea laticauda* may be associated with these and other biological fouling organisms in the water column because these habitats contain food resources that *S. laticauda* can exploit. However, isopods would not need to rely solely on biologically fouled habitat for food resources as this study established *S. laticauda* as a generalist, capable of utilizing food resources, such as benthic invertebrates, from other nearby habitats. It is likely that this isopod would persist in the bay if the biologically fouled habitats it is currently associated become unavailable.

While this study identified a potentially broad diet for *S. laticauda* in Delaware Bay, there were limitations with its design. This study only examined starved adult *S. laticauda* within a single temperature-salinity regime. Future studies could include adult and juvenile isopods maintained under a variety of environmental condition. Beyond including additional fauna and flora species, it would be valuable to address the issue of prey preference. This would help pinpoint species in Delaware Bay likely to experience the greatest predation pressure due to the continued presence of *S. laticauda*. Finally, cannibalism was documented during the temperature-salinity challenges as described in the previous chapter. Although it is not discussed here, the impact of cannibalism on the *S. laticauda* population should be investigated further.

Synidotea laticauda was identified in the gut contents of fish collected from the Nantuxent and Maurice Rivers, but, with one exception, were absent in fish collected from open waters of Delaware Bay. Fish collected from the Nantuxent and Maurice Rivers included white perch (*Morone americana*), white catfish (*Ameiurus catus*), American eel (*Anguilla rostrata*), and the oyster toadfish (*Opsanus tau*). The gut contents of these fish consisted primarily of crustaceans, mollusks, and small fish, as reported in previous studies. White perch consume small fish, shrimp, crabs, and vegetative debris (Hildebrand and Schroeder 1972; Scott and Scott 1988). Weiss (2005) reported unidentified isopods in the gut contents of white perch from the Hackensack River, NJ. American eels consume crustaceans, insects, small fish, snails, polychaetes, and occasionally vegetative material and isopods (Ogden 1970; Hildebrand and Schroeder 1972). Oyster toadfish primarily prey on crustacean, and in particular small crabs; however, they will consume mollusks, small fish, and the occasional isopod (McDermott 1964; Hildebrand and Schroeder 1972).

Fish collected from the open waters of Delaware bay included Atlantic croaker (*Micropogonias undulatus*), weakfish (*Cynoscion regalis*), black sea bass (*Centropristis striata*), and summer flounder (*Paralicthys dentatus*). Although summer flounder are reported to prey on fish, shrimp, and crabs (Hildebrand and Schroeder 1972; Powell and

Schwartz 1979), there was no food in the guts of the flounder collected for this study. The gut contents of other species were consistent with previous studies. Although Atlantic croaker prey on small fish, crustaceans, and mollusks, they are opportunistic feeders and frequently ingest both sediment and vegetative debris as they graze along the bottom. Juvenile Atlantic croaker diets consist primarily of polychaetes, crabs, and copepods (Hildebrand and Schroeder 1972; Stickney et al. 1975; Bullock 1986). The diet of juvenile weakfish is mostly crustacean, whereas the diet of the adult weakfish is primarily clupeid fish (Hildebrand and Schroeder 1972; Merriner 1975; Stickney et al. 1975). Juvenile black sea bass consume small crustaceans, including isopods, whereas the adults prefer small fish, crabs, and echinoderms (Hildebrand and Schroeder 1972; Bullock 1986).

Although the diets of many estuarine fish consist primarily of small invertebrates and fish (Bond 1979; Juanes et al. 2002), many species are opportunistic and forage on a variety of prey items (Elliott et al. 2001). Fish have evolved a variety of foraging strategies to take advantage of their particular morphology, habitat, and available food resources (Cailliet et al 1986). For example, mouth position and size influence a fish's ability to capture prey located above, below, or directly in front of it (Aleev 1963). Variations in foraging strategy could account for the appearance of *S. laticauda* in the gut contents of fish collected from Delaware Bay tributaries and absent from the gut contents of fish collected from the open waters of the bay itself.

It does not appear that the fish caught in the open waters of the bay use foraging strategies suited to prey on *S. laticauda*. Adult weakfish, for example, are pelagic piscivorous and unlikely to encounter the isopod while foraging. Juvenile weakfish, which consume small benthic invertebrates, and potentially *S. laticauda*, were not sampled in this study. Atlantic croaker and black sea bass are reported to consume benthic invertebrates, including isopods, yet only one was captured that had consumed an isopod. One reason may be that Atlantic croaker and black sea bass are not foraging in areas of Delaware Bay colonized by *S. laticauda*. The presence-absence survey described in the previous chapter documented *S. laticauda* in several open water areas of the bay, however, isopods were only observed clinging to anthropogenic structures located in the water column. Researchers from HSRL have not noted the isopods presence during routine dredge collections in the bay.

In contrast to those fish caught in the open water, those that were caught inshore do occur in the same habitat as *S. laticauda*. While these fish are more likely to encounter *S. laticauda*, they are not necessarily incorporating them into their diets. The gut contents of fish that were found to consume *S. laticauda* indicate that they are only an occasional component of their diet. Of the 15 fish found with isopods in their guts, 12 contained a single isopod, while 3 others contained two isopods. The low numbers of isopods present in the guts of these fish may be the result of naïve predators, which are unaccustomed to their capture. S*ynidotea laticauda* are frequently found on anthropogenic structures and their cryptic coloration may make it difficult for visual predators to locate them. The legs of *S. laticauda* have hooks at the end that allow them to cling to substrate, making them difficult to remove (personal observation). When *S. laticauda* were fed to *Fundulus heteroclitus* maintained in a HSRL aquarium the isopods were observed clinging to the outside of the mouth of the fish and it appeared that the fish had difficulty in manipulating the isopod before consuming it.

There were a number of limitations in the collection of fish for the present study. Small and unequal sample sizes were the primary limitations and prevented the use of stronger statistical analysis. Gut content analysis was initially intended only for fish caught in immediate proximity to isopod habitat in the Maurice River. The addition of samples from the bay was unanticipated and both the fish species and individual fish sampled were influenced by the various methods of collection. Recreational fishermen provided the majority of the fish collected from the bay, but were selective in the species they targeted. Minimum size regulations on summer flounder and weakfish imposed by the NJDEP likely influenced the number and size of fish being provided by the fishermen. Recreational fishing occurred in the morning and with baited hook-and-line. In contrast, the fish provided by the NJDEP were caught throughout the day in a trawl survey, and the multi-species trap was deployed for 24-h intervals in one location.

Both the design and deployment of the multi-species trap influenced the species of fish collected inshore. Fish larger than the 15-cm diameter funnel shaped entrance were unable to enter the trap, while it was possible for small fish to escape the trap through the 3.5-cm mesh. The multi-species trap was positioned near the river bottom and in close proximity to wooden pilings. The objective of the trap location was to maximize the opportunity for catching fish that occur in areas were the isopod density is high. This precluded catching species of fish that occur elsewhere in the water column, and those species that avoid structure. The trap was baited differently in the Maurice River and Nantuxent River, with catfish (*Ameiurus catus*) and white perch (*Morone americana*) used in the Maurice River and Atlantic menhaden (*Brevoortia tyrannus*) in the Nantuxent River. The oils released by the bait may have attracted different species of fish. Finally, traps deployed in the Maurice River were sampled in the morning whereas those in the Nantuxent were sampled in the early afternoon. Although the trap was deployed for 24 h at each location the sampling time may have influenced the composition of the catch.

In conclusion, the identification of several potential prey items supports the hypothesis that *S. laticauda* is capable of exploiting several local food resources. The ability to consume multiple fauna and flora from the bay makes the isopod a generalist; a trait which favors the successful establishment of non-indigenous species. At least four fish species are incorporating this isopod into their diets, it is clear that these fish are not exerting enough predation pressure to limit or prevent the occurrence of *S. laticauda* throughout Delaware Bay. Limited of predation pressure favors the successful establishment of non-indigenous species and points to the continued presence of *S. laticauda* in the bay. Therefore, the present study indicates that the availability of ample food resources and the limited impact of predation by fish favor the permanent establishment of *S. laticauda* in Delaware Bay.

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Table 3.1 *In vitro* feeding trials of *Synidotea laticauda* identifying potential food resources in New Jersey coastal waters. Consumption of prey item observed (+) and not observed (-) over 48-h.

Prey Item	Notes	Consumed	Replicates
Live			
Nereid Worms	Collected from oysters obtained from lower Delaware Bay and held in the HSRL conditioning system; worm length approximately 2-cm in the first trial and 3-cm in remaining trials	+	6
Zooplankton	Crab zoea and megalopae collected from the Maurice River with a 500-µm plankton net	+	4
Branching Bryozoans	Growing on docks located in the Maurice River	+	6
Juvenile *S. laticauda*	Collected from gravid *S. laticauda*; juveniles approx. total length was 2 mm	+	4
Anemone	Collected from oysters obtained from lower Delaware Bay and held in the HSRL conditioning system; anemones diameter was approx. 1 cm	-	4
Dead			
Crassostrea virginica	Oysters cultured at HSRL; shell height approx. 2.5 cm; presented with one valve removed	+	4
Callinectes sapidus	Collected from wire-mesh cages deployed in the Maurice River; Carapace cracked open to expose meat	+	2
S. laticauda	Dead adult *S. laticauda* collected from an aquarium maintained at HSRL	+	4
Plant			
Ulva sp.	Growing on docks located in the Maurice River	+	6
Spartina alterniflora	Collected from shoreline of the Maurice River	+	4
Fucus sp.	Collected from rocky shore in Atlantic Ocean (Cape May)	-	4
Unidentified Fungus	Growing on oysters obtained from lower Delaware Bay and held in the HSRL conditioning system	-	4

Table 3.2 Summary of fish caught for gut content analysis. Data are number of individuals collected weekly of white perch (*Morone americana*), oyster toadfish (*Opsanus tau*), white catfish (*Ameiurus catus*), American eel (*Anguilla rostrata*), Altantic croaker (*Micropogonias undulatus*), weakfish (*Cynoscion regalis*), summer flounder (*Paralicthys dentatus*), and black sea bass (*Centropristis striata*). Footnotes provide additional collection details, • indicate number of fish with a single *S. laticauda* collected from gut contents, ○ indicate number of fish with a two *S. laticauda* collected from gut contents

Date	**White Perch**	**Oyster toadfish**	**White catfish**	**American eel**	**Atlantic Croaker**	**Weakfish**	**Summer flounder**	**Black sea bass**
June								
1 - 7	3[a]	1[a]•						
8 - 14	1[a]							
15 - 21	1[a]		1[a]					
22 - 30	14[a]	3[a]•	1[a]	1[a]•				
July								
1 - 7	1[a]		2[a]•					
8 - 14	12[a]•		4[a]••					
15 - 21	8[a]•○							
22 - 28	2[a]•		1[a]		29[d]		5[d]	
29 - 31								
August								
1 - 7								
8 - 14				1[a]	6[d]•			
15 - 21	3[b]••○				40[e]	16[d]	2[c]	3[e]
22 - 28	6[b]•	4[b]						
29 - 31		12[b]						
Total	**51**	**20**	**9**	**2**	**75**	**16**	**7**	**3**

a – Caught in the Maurice River with multi-species trap (39º 14” 01’ N 75º 01” 51’ W)
b – Caught in the Nantuxent River with multi-species trap (39º 17 ‘06” N 75º 13” 48’ W)
c – Caught by fishermen participating in weakfish tournament held August 19th, 2006
d – Caught by fishermen aboard the *Miss Fortescue*
e – Caught by state biologist conducting trawl survey on August 16th, 2006

Table 3.3 Fish collected during summer of 2006 from Delaware Bay and examined for *Synidotea laticauda* in gut contents. Weight = whole wet weight (g) and Length = total fork length (cm) nd = no data available.

Species	N		Mean	SE	Min.	Max.
Morone americana	51	Weight	125.3	9.5	9.2	283.2
	51	Length	19.4	0.4	15.5	26.0
Opsanus tau	20	Weight	286.2	27.9	82.0	465.8
	20	Length	24.2	0.8	17.0	28.0
Ameiurus catus	8	Weight	409.8	200.7	79.2	1500.0
	8	Length	27.6	3.4	18.5	41.0
Anguilla rostrata	2	Weight	118.0	69.2	48.9	187.2
	2	Length	37.75	7.2	30.5	45.0
Micropogonias undulatus	38	Weight	33.4	2.2	16.59	71.24
	66	Length	22.1	1.1	12.50	36.00
Cynoscion regalis		Weight	nd	nd	nd	nd
	13	Length	37.3	0.6	34.0	41.0
Paralicthys dentatus		Weight	nd	nd	nd	nd
	5	Length	42.2	1.6	39.0	48.5
Centropristis striata	3	Weight	37.7	4.8	28.0	42.5
	3	Length	12.8	0.6	12.0	14.0

Table 3.4 Proportion of fish consuming *S. laticauda.* N= total number of fish, N_f = number of fish with food in gut, N_e = number of fish with empty guts, N_i = number of fish with *S. laticauda* in gut, F_i = frequency of isopod occurrence.

Species	N	N_f	N_e	N_i	F_i
Collected Inshore					
Morone americana	51	24	27	9	0.37
Opsanus tau	20	14	6	2	0.14
Ameiurus catus	9	6	3	3	0.50
Anguilla rostrata	2	1	1	1	1.00
Collected in Bay					
Micropogonias undulatus	75	45	30	1	0.02
Cynoscion regalis	16	12	3	0	0.00
Paralicthys dentatus	7	0	7	0	0.00
Centropristis striata	3	3	0	0	0.00

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