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DISTRIBUTION AND ABUNDANCE OF MYSIDS IN THE CUMBERLAND BASIN, UPPER BAY OF FUNDY

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The distribution and abundance of two species of mysids, *Neomysis americana* and *Mysis stenolepis*, in the Cumberland Basin was studied on monthly cruises from March to October 1981 and 1982. Maximum numbers and biomass occurred in summer and early fall respectively, with lower values in March and October. *N. americana* was the dominant species, averaging up to 10 adults m^{-3}; this species produced two generations per year, the first in May-June and the second overwintering generation in September-October. *M. stenolepis* produced one generation per year in May-June. Despite high turbidity and tidal currents, adult *M. stenolepis* demonstrated limited vertical migration, with greater numbers observed in the upper 2 m at night than in daylight hours. *Spartina* detritus was present in the gut of mysids throughout the study and suspended in the water at concentrations that potentially could support the mysid populations.

L'auteur a étudié la distribution et l'abondance de deux expèces de myside *Néomysis americana* et *Mysis stenolepsis* dans le Bassin de Cumberland au cours des croisières mensuelles de mars à octobre 1981 et 1982. Les maxima en nombre et en biomasse se trouvent en été et en automne respectivement avec les niveaux plus bas trouvés en mars et en octobre. *N. americana* est l'espèce dominante moyennant jusqu'a 10 adultes m^{-3}. Cette espèce produit deux générations par an, la première en mai-juin et la deuxième génération passant l'hiver en septembre-octobre. *M. stenolepsis* produit une génération par an en mai-juin. Malgré une turbité élevée et les courants de marée, l'adulte *M. stenolepsis* manifeste une migration verticale limitée. Dans la couche supérieure d'eau (2m) on observe un plus grand nombre le jour que la nuit. Les detritus de *Spartina* ont été présent dans le boyau des mysides pendant toute la période de l'étude et ont été suspendus dans l'eau à des concentrations qui pourraient entretenir les populations de mysides observées.

Introduction

The distribution and abundance of mysids in the upper reaches of the Bay of Fundy, which are typified by high turbidity and extreme tidal ranges, are poorly understood. The existence of large numbers is suggested by the observations of Leim (1924) in the Minas Basin, Hildebrand (1981) in Shepody Bay and Uhazy (1980) in the Cumberland Basin. Possibly the best indicator of their abundance is that they are commonly found in the guts of fish, especially American shad (*Alosa sapidissima*) which migrate into the region from June to October (Leim 1924). Dadswell *et al.* (1983) noted that the turbid water in the Cumberland Basin reduces the mean swimming depth of shad to between 5.4 and 9.2 m. Although there have been no quantitative studies relating the biomass of fish to biomass of mysids consumed in the upper reaches of Fundy, these authors conclude that shad, as a filter feeding planktivore, could eat these organisms.

Many biological investigations of mysid species, particularly *Neomysis americana,* have been conducted along the east coast of North America because of their abundance and importance as food for fish and possible role as consumers of detritus (e.g. Maurer & Wigley 1982; Williams 1972; Herman 1963). It has been suggested that mysids and zooplankton in the upper Bay of Fundy derive a substantial amount of their energy from *Spartina* detritus (Gordon *et al.* 1985b). To clarify the importance of macroplankton in this turbid environment and possible links between detritus and fish, I undertook a study of the species distribution and relative abundance of mysids in the shallow depths of the Cumberland Basin during months when shad are present. This is a contribution to studies in the upper reaches of Bay of Fundy, an area which has received increased attention during the past decade in response to proposals for tidal power development (Gordon and Dadswell 1984).

Study Site

The study was conducted in the Cumberland Basin, a 118 km² estuary at the head of the Bay of Fundy (Fig. 1). The mean tidal range is approximately11 m and can reach 16 m on high spring tides. Strong tidal currents averaging 0.6-1.0 m sec^{-1} (Amos and Asprey 1981) create very turbid conditions; concentrations of suspended sediment vary from 0.1 to 1.0 g L^{-1} and increase with depth and towards the head of the Basin. Salinity along the estuary varies between 22 ‰ and 34 ‰ and temperature, which is often uniform from surface to bottom, has a winter minimum of -1.5°C and a

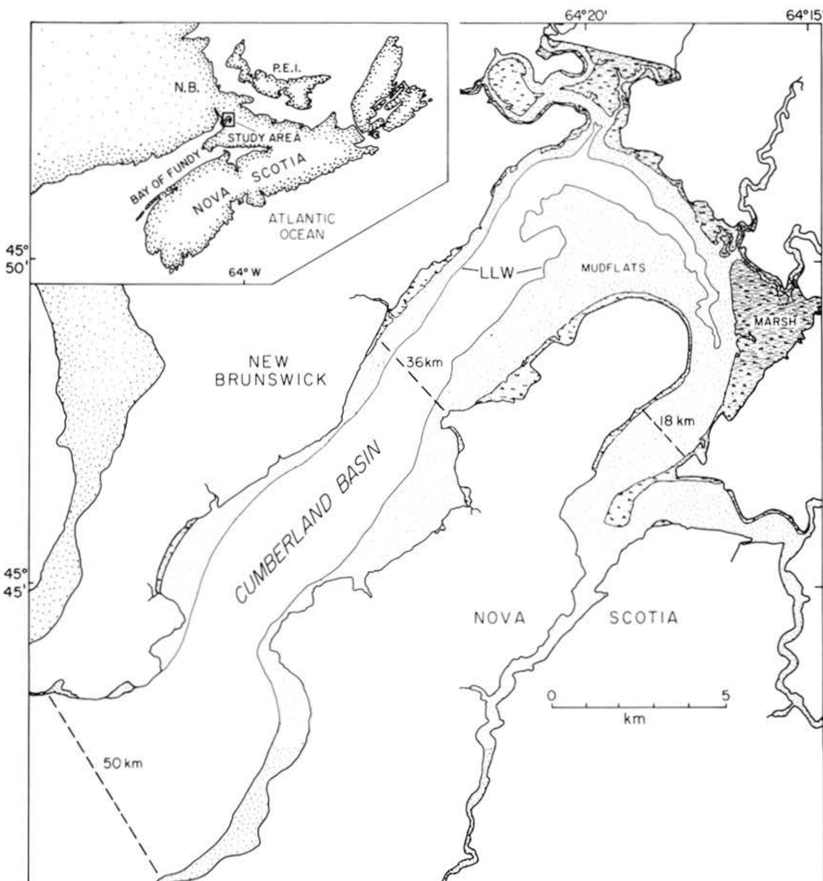

Fig 1 Map of the Cumberland Basin showing major salt marsh and mudflat areas, approximate tidal excursion limits and distance seaward from the head of salt water at mean high tide. LLW indicates lowest low water.

summer maximum of 18°C. Depth at mean sea level averages 7 and 12 m for the inner and outer Basin respectfully. The Cumberland Basin is typified by large tracts of saltmarsh dominated by *Spartina alterniflora* (Gordon *et al.* 1985a) and extensive mudflats.

Methods

Mysids were collected monthly from a local fishing boat from June to October in 1981 using a 0.5 m diameter 600 μm mesh plankton net towed at a mean depth of 6 m. Although this mesh size underestimated the number of juvenile mysids, it efficiently caught adult mysids and did not clog with the high amounts of macrodetritus in the water. The net was fitted with a General Oceanics digital flowmeter to determine the volume of water sampled. Continuous tows of 30 min. duration each were made over one complete tidal cycle throughout the Cumberland Basin. A second series of samples was collected monthly from either the RV J.L. Hart or a local fishing boat between March and September (except July) in 1982; nets similar to those used in 1981 were towed for one hour continuously over one or two complete tidal cycles at the mouth of the Basin. Most samples were collected in duplicate with one net deployed near the surface (0 - 2 m) and the other at a fixed midwater depth ranging from 2 - 19 m.

Contents of tows were preserved in 5% formalin. Results from tows taken in 1982 were used for biomass and number estimates since measured volumes of water filtered were recorded from attached flowmeters. Samples were split in the laboratory with a Motoda zooplankton splitter and the mysids separated from the macrodetritus using a density gradient method by centrifuging with LUDOX solution (Schwinghamer *et al.* 1983). Mysids were identified, sorted into stages as juvenile or adult (immature or mature) according to size and counted. Juveniles had no secondary sexual characteristics and were less than 6 mm in body length. Mysid wet weights were measured to calculate biomass per unit volume seawater. Actual numbers and biomass per m^3 of seawater were averaged for each sampling date, both for daylight and nighttime hours and the entire day.

The detritus was dried and weighed to calculate the amounts and distribution of macrodetritus for a concurrent study (Gordon *et al.* 1985b) and to test for correlations with mysid population distribution. Mysid numbers were analyzed to confirm any vertical movements through the water column. Statistical tests on the data used BMDP programs (Dixon and Brown 1979).

During the 1982 sampling, the location of the tows was standardized to the potential location the water mass would occupy at mean high water (Gordon *et al.* 1985b). Estimated current velocities are higher than the maximum swimming velocity of mysids as *Neomysis americana* (Hargreaves 1982) so they could be swept to these high tide positions.

The respiratory potential of mysids in the water column was estimated from the multiple regression of oxygen uptake by *Diaptomus* (Comita 1968). Using published data to confirm realistic values for mysids, this regression accounted for 56% of actual oxygen consumption in *Neomysis americana* (Smith and Hargreaves 1984) and *Neomysis awatschensis* and *Archaeomysis grebnitzhui* (Jawed 1973).

Results

Neomysis americana and *Mysis stenolysis* were the only mysid species collected during the study. In March of 1982 no *N. americana* were collected and only 0.02 *M. stenolepis* m^{-3} were captured at the mouth of the Basin. *N. americana*, present in all

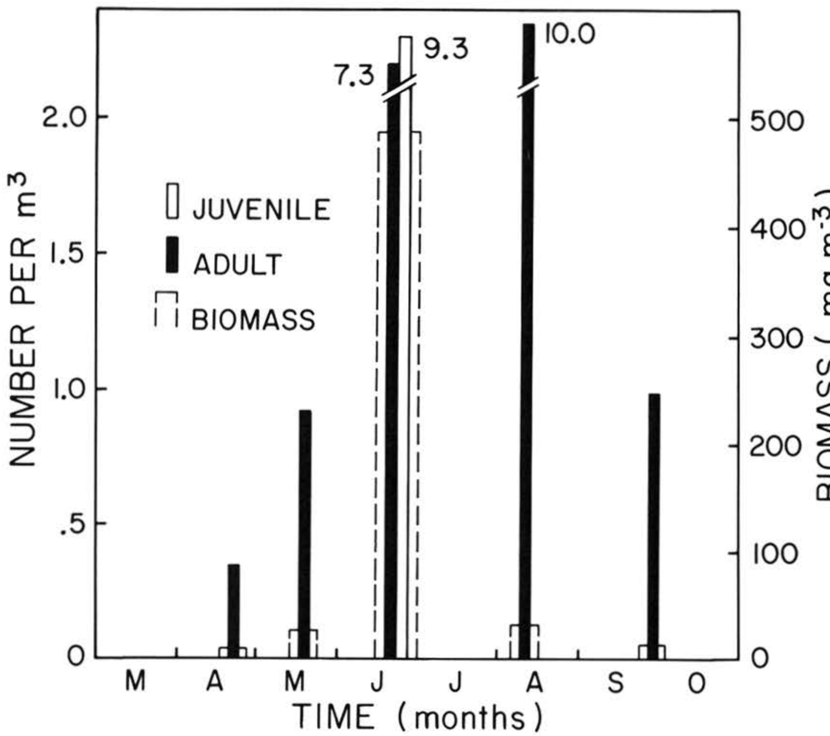

Fig 2 Average daily number and biomass per m³ of *Neomysis americana* collected at mid-depth from the Cumberland Basin in 1982.

samples collected in successive months, was the dominant species in numbers from April to September and in biomass from June to August (Fig. 2). Large numbers of juvenile *N. americana*, averaging 73 m^{-3} at midwater depths, were caught in June. These developed into immature adults by August which gave the maximum average population density of 10.0 *N. americana* m^{-3} in 1982. Biomass followed the same general pattern with very low weights in spring which rapidly increased to the maximum biomass of 488 mg wet weight m^{-3} in June. This resulted from the presence of overwintering and gravid adults as well as many juveniles. Biomass decreased to 5.5 mg wet weight m^{-3} by September. Some of the summer generation had matured by the end of September and were ovigerous; a few juveniles representing the second generation for the year were observed at this time.

M. stenolepis was not collected in June 1982. No sampling was carried out in July. From observations during 1981, it appears that *M. stenolepis* has one generation per year. Juveniles from overwintering adults were first encountered in May. Adults, all of which were female, disappeared from the population in June and the juveniles matured to reach a maximum biomass of 35.9 mg wet weight m^{-3} in September 1982 (Fig. 3). This also corresponds to the maximum average population of *M. stenolepis* of 0.13 mysids m^{-3} during the study. Observation in 1981 indicated *M. stenolepis* had a similar pattern of abundance to that in 1982 except for a summer peak, after which the population decreased to low numbers in October.

Location of the tows at mean high water along the axis of the estuaries in 1982 was plotted against the total mysid biomass in each tow (Fig. 4). There was significant

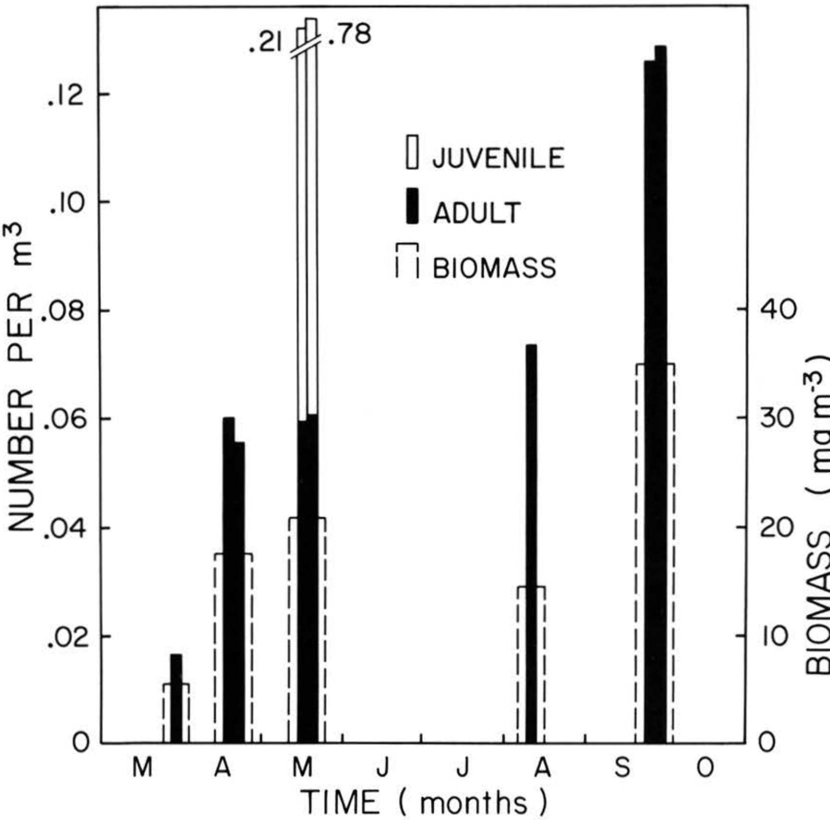

Fig 3 Average daily number and biomass per m³ of *Mysis stenolepis* collected at mid-depth from the Cumberland Basin in 1982.

positive correlation ($r^2 = 0.29$, $n = 160$, $p < 0.001$) between increasing biomass and location toward the head of Cumberland Basin. Similarly, macrodetritus greater than 600 μm, 85% of which is clearly of *Spartina* origin, and suspended sediment also increased in this direction (Gordon *et al.* 1985b; Amos and Asprey 1981). There was no significant correlation between the abundance of each species and the amount of suspended *Spartina* macrodetritus in the water.

Average number of each species per m³ collected in shallow and mid water depths during day and night (Tables I & II) were analyzed for possible diurnal movement. There were significantly more adult *M. stenolepis* in deeper water during daylight hours ($t = -3.81$, $p < 0.001$, $df = 81.9$) but there was no avoidance of surface water at night; vertical migration was probably initiated at the onset of darkness. No significant differences in the vertical distribution of adult *N. americana* nor the juveniles of each species was observed. Using a t test, there was also no significant difference in number and biomass of mysids between ebb and flood tides.

Oxygen consumption was calculated from biomass of both species per m^{-3} over the study period with correction for temperature differences in various sampling dates. The total amount of oxygen consumed was expressed as organic carbon to determine the feeding potential of mysids in the estuary and to compare this to a food

Table I Average number of adult *Neomysis americana* per m³ collected during day and night sampling at shallow (0-2 m) and midwater (2-19 m) depths from the Cumberland Basin in 1982. N = number of tows.

	Shallow				Midwater			
Date	Mean	Range	± SD	N	Mean	Range	± SD	N
Day								
March 30					0.00			6
April 19								
April 20					0.03	0.00-0.12	0.05	6
April 21	0.00			1	0.12	0.06-0.34	0.14	6
April 22	0.00			3	0.00			3
May 18	0.47	0.02-2.16	0.76	7	1.40	0.00-4.74	1.68	7
May 19	0.06	0.00-0.22	0.10	4	0.25	0.05-0.44	0.19	4
June 23					9.24	0.62-25.84	6.99	14
August 12					10.03	0.11-45.18	15.00	9
September 27	3.00			1	1.32			1
September 28	0.36	0.00-1.09	0.63	3	0.81	0.17-1.03	0.23	3
September 29	0.07			1	0.95			1
Night								
Date	Mean	Range	± SD	N	Mean	Range	± SD	N
March 30								
April 19					<0.01			4
April 20					0.01	0.00-0.03	0.01	10
April 21	0.01	0.00-0.02	0.01	2	<0.01	0.00-0.01	0.01	4
April 22	0.12	0.01-0.29	0.15	3	1.79	0.01-3.97	2.01	3
May 18	0.07	0.00-0.12	0.06	3	0.48	0.00-2.14	0.75	8
May 19	1.53	0.45-2.54	0.96	6	1.49	0.07-3.59	1.37	6
June 23					9.59	8.57-10.13	0.88	3
August 12								
September 27								
September 28	1.58	0.80-2.82	0.83	6	0.88	0.20-1.87	0.70	6
September 29	1.58	0.08-2.19	0.79	3	1.76	0.71-2.55	0.89	4

Table II Average number of adult *Mysis stenolepis* per $m^3 \times 10^{-2}$ collected during day and night sampling at shallow (0-2 m) and midwater (2-19 m) depths from the Cumberland Basin in 1982. N = number of tows.

				Day				
	Shallow				Midwater			
Date	Mean	Range	± SD	N	Mean	Range	± SD	N
March 30					1.56	0.65-2.50	0.71	6
April 19								
April 20					4.02	0.00-12.20	4.64	6
April 21	0.00			1	4.77	0.00-12.86	5.05	6
April 22	0.03	0.00-0.09	0.05	3	0.00			3
May 18	2.89	0.00-10.54	3.99	7	10.40	0.00-35.85	13.74	7
May 19	0.00			4	0.16	0.00-0.62	0.31	4
June 23					0.00			14
August 12					7.36	0.00-35.42	14.25	9
September 27	1.20			1	5.07			1
September 28	0.92	0.00-8.45	2.65	10	12.12	5.39-26.18	6.61	11
September 29	0.00			1	23.24			1
				Night				
	Shallow				Midwater			
Date	Mean	Range	± SD	N	Mean	Range	± SD	N
March 30								
April 19					0.06	0.00-0.23	0.12	4
April 20					4.57	0.00-26.52	8.07	10
April 21	1.28	0.1-2.46	1.67	2	6.72	0.00-15.33	7.47	4
April 22	1.75	0.00-4.05	2.08	3	7.04	0.01-12.21	6.32	3
May 18	0.15	0.00-0.44	0.25	3	2.54	0.00-10.85	4.03	8
May 19	10.54	0.00-16.67	6.66	6	10.13	0.55-25.53	8.37	6
June 23					0.00			3
August 12								
September 27								
September 28	5.85	0.00-26.67	8.09	10	12.65	2.28-32.93	9.15	10
September 29	3.60	0.39-7.86	3.49	5	11.12	5.05-18.69	5.14	5

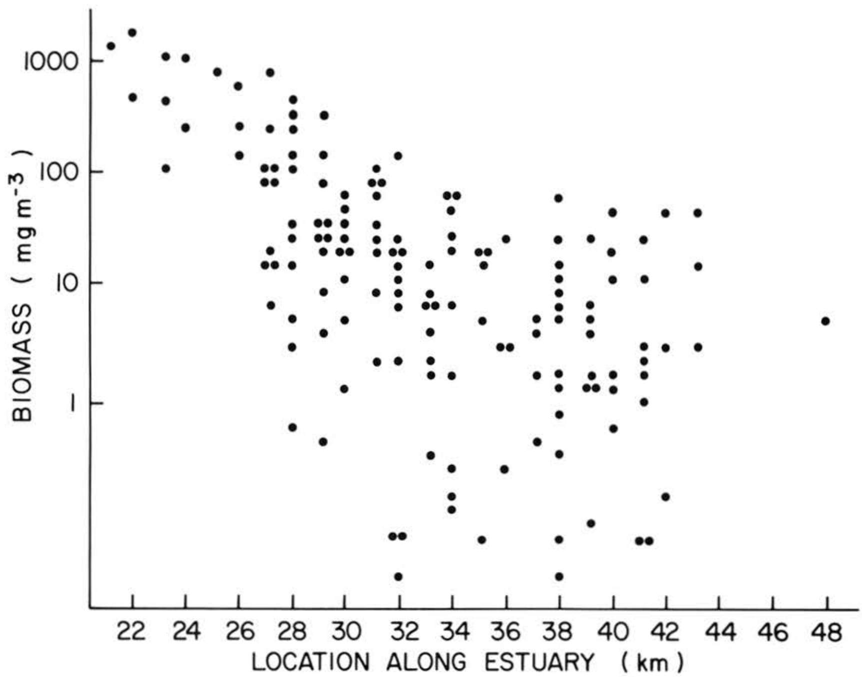

Fig 4 Biomass of mysids collected from each sample tow in the Cumberland Basin plotted against location corrected to high tide position.

supply potentially available as macrodetritus. This varied from 0.001 to 0.510 mg C m^{-3} respired per day. From a concurrent study, the mean concentration of *Spartina* detritus in the water column was 15 mg m^{-3} (Gordon *et al.* 1985b) which represents 4.5 to 6.5 mg C m^{-3} (Gordon *et al.* 1985a).

Discussion

Observations over two sampling seasons in Cumberland Basin showed that changes in mysid propulation structure and abundance were similar to other temperate areas; there are distinct seasonal fluctuations in mysid populations in all temperate regions. Hopkins (1965), amongst others, described how *N. americana* is abundant in the Delaware estuary from April to September and had a summer maximum in surface tows of 3300 m^{-3} in June and 800 m^{-3} in July. *N. americana* in the Cumberland Basin appears to have a similar pattern, increasing from low numbers in March - April to a maximum in summer as a result of breeding, then declines in numbers in September - October. *M. stenolepis,* with low numbers in spring, a population maximum in September, and possible low abundance in fall, also has these seasonal fluctuations. Life histories of *N. americana* and *M. stenolepis* in the Basin, with two and one generations per year respectively, are in agreement with those described for the same species near the mouth of the Bay of Fundy (Pezzack and Corey 1979; Amaratunga and Corey 1975).

N. americana was the dominant species of mysid, as has been observed in other areas along the east coast of North America (e.g. Hopkins 1965; Wigley and Burns

1971; Williams 1972). Although population abundance (average number per m^3) seems low in comparison to observations in other areas, *N. americana* is relatively abundant. For example, one tow in June 1982 had 25 adults and 261 juveniles m^{-3}. As stated by Hulbert (1957), a population of *N. americana* greater than 10 m^{-3} is a "relatively large concentration".

The decline in number of mysids in summer-early fall might be partly due to predation by the American shad *Alosa sapidissima*. Large numbers of shad, originating along the entire Atlantic coast of North America, migrate into the upper reaches of Fundy from June to October, peaking in July (Dadswell *et al.* 1983). This is the most important large pelagic fish to enter the Cumberland Basin and individuals concentrate at shallow depths. Leim (1924) found that *N. americana* was the major food source of mature shad in nearby Scotsman Bay. Similarly, adult shad along the Pacific coast in the Sacramento - San Joaquin Delta of California were shown to feed primarily on a slightly larger mysid, *Neomysis awatschensis* (Stevens 1966); the stomach of one shad contained in excess of 4000 mysids. Other pelagic fish as the alewife *Alosa pseudoharengus* and blueback herring *Alosa aestivalis* are also numerous in this area and have been observed to eat mysids (H. Stone unpublished data). In addition, *N. americana* is consumed by juvenile fish such as the American smelt *Osmerus mordax* and smooth flounder *Liopsetta putnami* in the upper Bay of Fundy (Imrie and Daborn 1981) and *M. stenolepis* is the "principal prey" of six species of fish, including white hake *Urophycis tenuis*, in Passamaquoddy Bay, lower Bay of Fundy (Tyler 1972).

The decline of mysid populations in the fall might also be due to the migration of animals to deeper water outside Cumberland Basin. Hopkins (1965) noted low numbers of *N. americana* in surface water of the Indian River Inlet, Delaware, during late fall and winter, perhaps in response to decreasing water temperature. Amaratunga and Corey (1975) observed that *M. stenolepis* in Passamaquoddy Bay moved to deeper water (20-50 m) in autumn, possibly to breed. Tows in Cumberland Basin were not deeper than 19 m nor were any made in late fall and winter so emigration cannot be verified. However, *M. stenolepis* was absent and *N. americana* in very low abundance, <1 mysid m^{-3}, in oblique tows taken at the mouth of the Cumberland Basin in February 1980 (G. Daborn unpublished data).

Movement of mysids, especially *N. americana* through the water column in response to light is well documented (eg. Hulbert 1957; Herman 1962; Hopkins 1965). Limited vertical migration in the Cumberland Basin with only adult *M. stenolepis* exhibiting significant diurnal movement could be the result of low light and strong tidal turbulence. High levels of suspended material in the Basin reduced the 1% depth of light penetration to less than 2 m (Prouse 1983) and on some occasions midday light levels at 1 m depth were below 4.25 Wm^{-2} (Prouse unpublished data from Hargrave *et al.* 1983). Mauchline (1980), reviewing mysid behavioral responses, pointed out that 10^3 to 10^4 lux (4.25 - 42.5 Wm^{-2}) inhibits mysid vertical movement towards the surface whereas 4×10^{-2} lux (2×10^{-4} Wm^{-2}) or less can initiate positive phototaxis. Thus the migratory response of mysids to light in the Basin would fluctuate greatly depending on the amount of suspended material and the incident radiation. In addition, very strong tidal turbulence could impede the swimming of mysids, especially the smaller *N. americana* and juveniles of both species, so that they are randomly mixed in the water column. *N. americana* has a routine swimming velocity of 7 cm sec^{-1} (Hargreaves 1982), whereas larger mysids such as *M. stenolepis* have a greater swimming speed and could perhaps have directed movement under highly turbulent conditions.

Mysids are omnivores, feeding on a great diversity of material (reviewed by Mauchline 1980). Diatoms can be a major food item (Siegfried and Kopache 1980; Kost and Knight 1975) and Fulton (1982a, b) recognized *N. americana* as a predator of copepods. Fulton also observed the dominance of unidentified detritus in the guts of *N. americana*. Teal (1962) has described how detritus from *Spartina alterniflora* can provide food for fauna of a Georgia saltmarsh and laboratory studies on *M. stenolepis* indicate an ability to digest cellulose (Foulds and Mann 1978; Wainright and Mann 1982). It is likely that the large amounts of salt marsh detritus in suspension originating from extensive *Spartina* marshes in the Cumberland Basin are an important energy source for mysids. Very high ingestion rates of *Spartina* detritus by *N. americana* have been observed in North Inlet, South Carolina (Zagursky and Feller 1985); when fed *Spartina* detritus in the laboratory these mysids consumed over 200% of their body carbon per day.

Preliminary observations by microscopic examination indicate that both species had *Spartina* detritus in their guts. Further, as calculated above, the carbon content of detritus suspended in the water was much greater than the daily carbon requirements for mysid respiration and could potentially support the population. It has been stated that mysids consume the most abundant food available (Raymont *et al.* 1964). As phytoplankton production is low, on the order of 15 g C m^{-2} y^{-1} (Prouse *et al.* 1984), and the copepod biomass is considerable but extremely patchy (Daborn 1984), *Spartina* detritus could be a major source of food for these organisms in the upper reaches of the Bay of Fundy.

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