The Effect of Wind Direction on the Abundance and Distribution of Decapod Crustacean Larvae in a Newfoundland Nearshore Area

G.P. Ennis

Fisheries Research Branch
Department of Fisheries and Oceans
P.O. Box 5667
St. John's, Newfoundland A1C 5X1

February 1983

Canadian Technical Report of Fisheries and Aquatic Sciences No. 1138

Government of Canada Fisheries and Oceans
Gouvernement du Canada Pêches et Océans

Canadian Technical Report of Fisheries and Aquatic Sciences

These reports contain scientific and technical information that represents an important contribution to existing knowledge but which for some reason may not be appropriate for primary scientific (i.e. *Journal*) publication. Technical Reports are directed primarily towards a worldwide audience and have an international distribution. No restriction is placed on subject matter and the series reflects the broad interests and policies of the Department of Fisheries and Oceans, namely, fisheries management, technology and development, ocean sciences, and aquatic environments relevant to Canada.

Technical Reports may be cited as full publications. The correct citation appears above the abstract of each report. Each report will be abstracted in *Aquatic Sciences and Fisheries Abstracts* and will be indexed annually in the Department's index to scientific and technical publications.

Numbers 1-456 in this series were issued as Technical Reports of the Fisheries Research Board of Canada. Numbers 457-714 were issued as Department of the Environment, Fisheries and Marine Service, Research and Development Directorate Technical Reports. Numbers 715-924 were issued as Department of Fisheries and the Environment, Fisheries and Marine Service Technical Reports. The current series name was changed with report number 925.

Details on the availability of Technical Reports in hard copy may be obtained from the issuing establishment indicated on the front cover.

Rapport technique canadien des sciences halieutiques et aquatiques

Ces rapports contiennent des renseignements scientifiques et techniques qui constituent une contribution importante aux connaissances actuelles mais qui, pour une raison ou pour une autre, ne semblent pas appropriés pour la publication dans un journal scientifique. Il n'y a aucune restriction quant au sujet, de fait, la série reflète la vaste gamme des intérêts et des politiques du Ministère des Pêches et des Océans, notamment gestion des pêches, techniques et développement, sciences océaniques et environnements aquatiques, au Canada.

Les Rapports techniques peuvent être considérés comme des publications complètes. Le titre exact paraîtra au haut du résumé de chaque rapport, qui sera publié dans la revue *Aquatic Sciences and Fisheries Abstracts* et qui figurera dans l'index annuel des publications scientifiques et techniques du Ministère.

Les numéros 1-456 de cette série ont été publiés à titre de Rapports techniques de l'Office des recherches sur les pêcheries du Canada. Les numéros 457-714, à titre de Rapports techniques de la Direction générale de la recherche et du développement, Service des pêches et de la mer, ministère de l'Environnement. Les numéros 715-924 ont été publiés à titre de Rapports techniques du Service des pêches et de la mer, Ministère des Pêches et de l'Environnement. Le nom de la série a été modifié à partir du numéro 925.

La page couverture porte le nom de l'établissement auteur où l'on peut se procurer les rapports sous couverture cartonnée.

Canadian Technical Report of
Fisheries and Aquatic Sciences 1138

February 1983

THE EFFECT OF WIND DIRECTION ON THE ABUNDANCE AND DISTRIBUTION OF DECAPOD CRUSTACEAN LARVAE IN A NEWFOUNDLAND NEAR-SHORE AREA

by

G. P. Ennis

Fisheries Research Branch
Department of Fisheries and Oceans
P.O. Box 5667
St. John's, Newfoundland A1C 5X1

This is the seventy-second Technical Report from
Fisheries Research Branch, St. John's, Newfoundland.

Minister of Supply and Services Canada 1983

Cat. No. Fs 97-6/1138 ISSN 0706-6457

Correct citation for this publication:

Ennis, G. P. 1983. The effect of wind direction on the abundance and distribution of decapod crustacean larvae in a Newfoundland near-shore area. Can. Tech. Rep. Fish. Aquat. Sci. 1138: iv + 19 p.

CONTENTS

ABSTRACT

Ennis, G. P. 1983. The effect of wind direction on the abundance and distribution of decapod crustacean larvae in a Newfoundland near-shore area. Can. Tech. Rep. Fish. Aquat. Sci. 1138: iv + 19 p.

Larvae of the crabs, Hyas araneus, Chionoecetes opilio, Cancer irroratus, and the lobster, Homarus americanus, were considerably less abundant in the near-shore area with offshore winds than with onshore winds. There was comparatively little change in the abundance of larvae of the hermit crabs, Pagurus arcuatus and P. acadianus, and the shrimp, Eualus pusiolus and an unidentified species, with different wind conditions. The apparent reason for this is that the hermit crab and shrimp larvae were much less concentrated at the surface than the other species.

Surface living larvae which originate in the near-shore area apparently can be returned to the coast from considerable distances when wind is onshore and recruitment to the near-shore adult population in these species is probably dependent upon onshore winds during the period when settling stage larvae are present in the plankton. However, the appearance of megalopae of C. irroratus in the near-shore area late in the larval period in much greater abundance than the intermediate stages indicates the possibility of some mechanism in addition to wind driven surface currents for their return to the coast when ready to settle. Those larvae which are found mainly below the surface are presumably more active vertical swimmers and possibly maintain position near parental grounds as a recruitment mechanism.

Key words: wind direction, abundance, distribution, decapod larvae, near-shore

RÉSUMÉ

Ennis, G. P. 1983. The effect of wind direction on the abundance and distribution of decapod crustacean larvae in a Newfoundland near-shore area. Can. Tech. Rep. Fish. Aquat. Sci. 1138: iv + 19 p.

Les larves des crabes Hyas araneus, Chionoecetes opilio et Cancer irroratus et du homard Homarus americanus sont beaucoup moins abondantes dans la zone littorale avec des vents de terre qu'avec des vents de mer. Il y a peu de changements dans l'abondance des larves de bernard-l'hermite Pagurus arcuatus et P. acadianus et de crevette Eualus pusiolus et d'une espèce non identifiée, sous des conditions différentes de vent. Ceci est probablement dû au fait que les larves de bernard-l'hermite et de crevette sont beaucoup moins concentrées à la surface que celles des autres espèces.

Il semble que les larves de surface qui proviennent de la zone littorale peuvent être ramenées de très loin vers la côte quand le vent souffle de la mer. Le recrutement de ces espèces dans la population adulte du littoral dépend donc probablement des vents de large pendant la période où les larves au stade de fixation sont présentes dans le plancton. Toutefois, l'apparition de mégalopes de C. irroratus dans la zone littorale, en nombres beaucoup plus importants à la fin de la période larvaire qu'aux stades intermédiaires, porte à croire à la possibilité d'un facteur autre que les courants de surface dus au vent, qui serait responsable de leur retour vers la côte quand elles sont prêtes à se fixer. Les larves retrouvées surtout sous la surface sont probablement des nageurs verticaux plus actifs. Le fait qu'elles restent près des aries parentales agit comme moyen de recrutement.

INTRODUCTION

There are six species of decapod crustacea (Hyas araneus, Cancer irroratus, Homarus americanus, Pagurus arcuatus, Pagurus acadianus, Eualus pusiolus) that commonly occur as adults on a narrow band of rocky bottom along the shoreline on the northeast coast of Newfoundland. This narrow band of rocky bottom is commonly referred to as "lobster grounds" and generally extends from the shoreline to depths of 25-30 m at around 50-100 m from shore. Beyond this the bottom is mainly sandy and usually slopes much less steeply.

During early summer each year these decapod species liberate tremendous numbers of larvae. Since, in settling, larvae of marine bottom invertebrates frequently show a preference for those areas of the bottom which are the habitat of adults of the same species (Thorson 1957), it is quite reasonable to assume that after a period (maybe several weeks or more) of larval development significant numbers of these decapod larvae eventually settle in this near-shore area.

Much uncertainty surrounds the question of how decapod larvae come to be near suitable bottom when ready to settle. There are at least three possible explanations: (1) larvae maintain position near parental grounds during development; (2) larvae relocate parental grounds when ready to settle; (3) larvae are carried passively by currents and their presence near suitable bottom when settling is fortuitous. There are mechanisms or combinations of mechanical and behavioral factors which indicate that (1) and (2) above are included in decapod larval recruitment. However, larvae of other invertebrate groups are sometimes ascribed a purely passive role with respect to distribution (see Makarov 1969 for references) and (3) above cannot be ruled out for decapod larvae. The mechanical factors mentioned include currents and current systems and the behavioral factors include vertical movement of larvae, their responses to light, pressure, etc., and active swimming against currents.

The main purpose of this study was to determine the effect of wind (hence surface current) direction on the abundance and distribution of decapod larvae in a near-shore area of the northeast coast of Newfoundland and thereby gain some understanding of the mechanisms of recruitment to the decapod populations in this area. Also examined, however, were various ecological relationships between the different larvae such as the degree of overlap in hatching periods between species and the relative abundance of the larvae of each species in the plankton.

MATERIALS AND METHODS

A diver-operated plankton collector (Ennis 1972) was designed specifically for this study. The collector consisted of two diver propulsion vehicles strapped together with specially-made clamps and a 50 cm plankton net (#2 mesh - 390 μ) supported in front. This made it possible to have good depth control in relatively shallow water and also to "tow" close to the bottom even where it was rough and uneven. Sampling was done throughout the period May to September, 1971, near St. Chads, Bonavista Bay, on the northeast coast of

Newfoundland. Sampling consisted of a set of five-minute tows at varying depths from surface to bottom at different distances (up to 20 m) from shore. Each set consisted of 5 to 7 tows done in succession. Individual tows filtered approximately 52 m^3 of water. Samples were preserved in 10% formalin for later examination when all decapod larvae were removed and sorted as far as possible by species and larval stage and counted. At the time of sampling observations were made on wind direction in relation to the shoreline and temperature was recorded at 3 m intervals from surface to bottom at 9 m.

RESULTS

EFFECT OF WIND

Decapod crustacean larvae found in the near-shore area along the northeast coast of Newfoundland can be grouped into three general categories with respect to their vertical distribution and the effect of wind direction on their abundance. The first category is represented by the rock crab, *Cancer irroratus*, and the toad crab, *Hyas araneus*. Larvae of these species were much more abundant at the surface than at depths from 3 to 9 m and were more abundant with onshore wind than with offshore wind (Tables 1 and 2). Lobster, *Homarus americanus*, larvae were taken only at the surface and only with onshore wind. Although they were taken very infrequently and in very small numbers, they are considered here to represent the second category. The third category is represented by hermit crab, *Pagurus arcuatus* and *P. acadianus* and shrimp, *Eualus pusiolus*, larvae which were more abundant in subsurface layers and whose abundance was little affected by wind direction.

There was tremendous variability in the abundance and distribution of each species and some of the more subtle effects of varying conditions may be masked by summarizing several sets of tows under similar conditions over the full sampling period. The results from a number of individual sets of tows are examined in relation to conditions at the time. The data from each set are provided in text tables and additional information is provided in the Appendix.

Cancer irroratus. With onshore wind larvae of *C. irroratus* were concentrated at the surface although some were taken as deep as 9 m (Sets 1, 2, and 3). The degree of concentration at the surface varied. In the six instances in Sets 1, 2, and 3 where a tow was done at the surface and at the 3 m depth in the same vertical plane, the percentage of larvae at the surface ranged from 67 to 97% of the total taken at both depths.

		Distance from shore/depth (m)				
	Depth (m)	<2/1.5	4/3	10/6	20/9	Temp. °C
Set 1	0	808	1211		558	8.3
	3		254		277	8.3
	6				173	8.3
	9				40	8.3
Set 2	0	2571	2180	2926		10.0
	3		78	299		9.9
	6			7		9.9
	9					9.9
Set 3	0	45	260	768		10.1
	3		43	170		10.1
	6			2		9.8
	9					9.8

The variation in concentration with depth was not attributed to temperature differences since temperature was essentially uniform from surface to 9 m. Within the surface layer the concentration of larvae varied with distance from shore but not in any consistent pattern.

In some instances (Sets 4, 5, and 6) surface concentration was much less pronounced than in the sets above and at times more larvae were taken at the 3 m depth than at the surface.

		Distance from shore/depth (m)				
	Depth (m)	<2/1.5	4/3	10/6	20/9	Temp. °C
Set 4	0				172	11.1
	3				255	10.7
	6				126	9.5
	9				10	9.0
Set 5	0		385		186	9.0
	3		40		74	9.0
	6				29	9.0
	9					7.9
Set 6	0	105	14		147	8.6
	3		62		118	8.4
	6					8.4
	9					8.5

Numbers of larvae taken with offshore wind (Sets 7, 8 and 9) were quite small in comparison with numbers taken with onshore wind and surface concentration was not evident.

		Distance from shore/depth (m)				
	Depth (m)	<2/1.5	4/3	10/6	20/9	Temp. °C
Set 7	0		2		0	8.4
	3		2		1	8.2
	6				0	7.9
	9				0	7.6
Set 8	0		7	3	3	10.0
	3		1	6	64	9.3
	6					8.1
	9					7.6
Set 9	0	22	17	6	7	15.2
	3		0	21		14.5
	6			1		14.1
	9					13.3

Under conditions of no wind (Sets 10, 11 and 12) there were large numbers of larvae taken. In some sets of tows (eg. Set 10) surface concentration was pronounced while in others (Sets 11 and 12) there were more larvae taken below the surface at some positions.

		Distance from shore/depth (m)				
	Depth (m)	<2/1.5	4/3	10/6	20/9	Temp. °C
Set 10	0	334	519		1602	9.9
	3		24		34	9.4
	6				6	8.6
	9					8.3
Set 11	0		997	621	47	8.8
	3		155		969	8.3
	6			71	252	8.0
	9					7.8
Set 12	0		116		213	9.9
	3		5		378	9.4
	6				165	8.5
	9					8.3

The variation in numbers of larvae taken at any one position at the surface was considerable and the number of samples were too few for detailed statistical analysis. However, the data for C. irroratus indicate that larvae at the surface tend to be concentrated in the near-shore area with onshore winds. Although sampling was done very close to shore there was no indication of larvae being swept ashore and destroyed. It seems likely that some sort of behavioral or mechanical shore-avoidance mechanism operates under such conditions.

C. irroratus was the only species whose megalopa stage was taken in appreciable numbers. Wind direction had the same effect on their abundance in the near-shore area as it had on the earlier stages (Table 3). In the case of these megalopae there was a clearer indication of a possible shore-avoidance mechanism. Concentration at the surface was even more pronounced than for early stages.

Hyas araneus. Larvae of H. araneus were taken in large numbers in just one set (Set 1) of tows made on July 3 with onshore wind.

		Distance from shore/depth (m)				
	Depth (m)	<2/1.5	4/3	10/6	20/9	Temp. °C
Set 1	0	67	422		52	8.3
	3		19		0	8.3
	6				2	8.3
	9				0	8.3

No tows were made with offshore wind close to this date but on the preceding day in the same area, again with onshore wind, only two larvae were taken indicating considerable day to day variability apparently independent of changes in wind direction. In the remainder of the sets of tows in which H. araneus larvae were taken, numbers were generally small and overall there was little indication of any effect of wind direction. There was little difference between numbers taken in a set of tows (Set 13) on June 7 with offshore wind and in a set (Set 14) done the following day with onshore wind.

		Distance from shore/depth (m)				
	Depth (m)	<2/1.5	4/3	10/6	20/9	Temp. °C
Set 13	0		2		17	6.4
	3		1		0	5.7
	6				0	5.5
	9					5.2
Set 14	0		5		5	6.5
	3		1		2	6.5
	6				1	6.5
	9				0	6.0

However, in two other sets of tows (Sets 2 and 8) done three days apart, there appeared to be an effect of wind with no larvae being taken with offshore wind (Set 8).

	Depth (m)	Distance from shore/depth (m) 2/1.5	4/3	10/6	20/9	Temp. °C
Set 2	0	0	3	32		10.0
	3		0	2		9.9
	6			0		9.9
	9					9.9
Set 8	0		0	0	0	10.0
	3		0	0	0	9.3
	6					8.1
	9					7.6

Homarus americanus. Lobster larvae were taken only at the surface and only with onshore wind (Tables 1 and 2). Usually just one or two stage I larvae were taken in any one five-minute tow but on one occasion seven were taken.

Chionoecetes opilio. Although this crab species is distributed in deep water (generally 165 m), its larval stages are found in the near-shore area. They were taken only with onshore wind and, except for a few specimens at the 3 m depth, they were taken only at the surface (Tables 1 and 2).

Pagurus arcuatus and P. acadianus. Larvae of these hermit crab species were taken infrequently and then only in very small numbers. There was little if any effect of wind direction and more were taken in subsurface tows, particularly at the 9 m depth, than at the surface (Tables 1 and 2).

Eualus pusiolus. Larvae of this shrimp species were generally taken in small numbers and somewhat more consistently in surface tows (Tables 1 and 2). Except for one subsurface tow with offshore wind that contained 46 larvae, there was relatively little difference in numbers taken either at or below the surface or with onshore or offshore wind.

Other shrimp species. Larvae of a second, unidentified shrimp species were taken fairly regularly. This species was taken more consistently and in greater numbers in subsurface tows, especially with onshore wind (Tables 1 and 2).

PERIODS OF LARVAL HATCHING

For those species of decapod crustacea that occur in the near-shore area (i.e., C. irroratus, H. americanus, H. araneus, E. pusiolus, P. arcuatus and P. acadianus) there is considerable overlap in the periods of larval hatching as demonstrated by the occurrence of newly-hatched (stage I) larvae in the plankton. C. irroratus hatches over the longest period (early June to mid September at least), followed by E. pusiolus (mid June to late August), P. arcuatus and P. acadianus (early June to early August), and H. araneus (early June to around mid July). Very few H. americanus were taken and these during the early to mid July period (Fig. 1). This overlap in hatching period

appears to be a favourable ecological situation for larvae of the lobster since they are considerably larger than the other decapod larvae and in rearing containers feed on them quite readily. Crab larvae, particularly those of C. irroratus, and E. pusiolus larvae probably form an important part of the natural diet of larval lobsters.

RELATIVE ABUNDANCE OF DIFFERENT LARVAE AND LARVAL STAGES

Early larval stages (I and II) of C. irroratus were much more abundant and were taken more consistently in the plankton than any other decapod species. In fact, on the average, they were more abundant than all other species combined (Table 4). Intermediate and late larval stages were generally taken only occasionally and in very small numbers compared to early stages. However, megalopae of C. irroratus were taken in fair abundance from mid to late August and were much more abundant than stages III and IV. This indicates the possibility of some behavioral mechanism, in this species at least, for their return to the coast when they reach the settling stage.

DISCUSSION

In the near-shore area along the northeast coast of Newfoundland, the abundance of those decapod larvae which tend to concentrate at the surface (i.e., C. irroratus, H. araneus, H. americanus, and C. opilio) depends very much on wind direction in relation to the shore. These larvae appear to be carried seaward by the surface currents when wind is offshore and there is no indication of downward movement to avoid this transport away from the parental grounds. The snow crab (C. opilio) occurs in deep water (generally 165 m) off the coast yet with onshore winds their larvae are found in the near-shore area, indicating that larvae can be carried away from shore for considerable distances and still be returned. Settlement of larvae in the near-shore area where they originate seems to be dependent on onshore wind prevailing during the period when larvae are ready to settle. Wind direction is quite variable in this area but, since these species have a fairly long hatching period and presumably a similarly long period when settling stage larvae would be present in the plankton, the chances of some being carried back to shore when ready to settle seem very good. However, the appearance of megalopae of C. irroratus in the near-shore area late in the larval period in much greater abundance than the intermediate stages indicates the possibility of some mechanism in addition to wind driven surface currents for their return to the coast when ready to settle.

The abundance in the near-shore area of those decapod larvae that live mainly below the surface (ie., P. arcuatus, P. acadianus, and E. pusiolus) varies very little in relation to wind direction. Presumably they are more active vertical swimmers and appear to be better able to maintain position near the parental grounds which provide suitable settling bottom.

Various larval recruitment mechanisms have been proposed for other decapod species in other areas. Larvae of the western rock lobster (Panulirus longipes cygnus) in Western Australia are transported considerable distances (as much as

1500 km) from the coast by offshore surface wind drift. Late stage larvae are transported back to coastal areas in coastward moving water underlying the surface layer (Chittleborough and Thomas 1969, Rimmer and Phillips 1979, Phillips 1981). Johnson (1974) similarly reports considerable offshore dispersal (up to 2000 nautical miles or more) of larvae of Panulirus penicillatus and P. gracilis from the west coast of Central America, apparently having drifted with the South Equatorial Current. The North Equatorial Countercurrent is suggested as a possible route for return of larvae to the adult habitat from lesser dispersal distances.

In a number of decapod species it has been suggested that larvae are retained in coastal areas where they originate by means of compensating and countercurrent systems. This was proposed for Panulirus interruptus and P. gracilis on the coast of California (Johnson 1960), for crabs of the family Xanthidae, again off the coast of California (Knudsen 1960), and for Panulirus argus in Bermuda (Lebour 1950).

Johnson (1960) also speculated that when phyllosomes of P. interruptus molt into the puerulus stage they quickly settle to the bottom while still in deep water and that some may migrate onshore to the shallow coastal nursery areas as benthic puerulus or postpuerulus forms. Serfling and Ford (1975), however, suggest that in P. interruptus the puerulus stage is pelagic, specifically adapted for directional swimming and capable of returning by active means to near-shore nursery areas suitable for settlement.

Although decapod larvae generally (particularly early stages) appear to be at the mercy of currents as far as horizontal displacement is concerned, there is strong evidence that they may move vertically to "ride" currents flowing in different directions as a means of remaining near parental grounds. Sandifer (1973) found that in a Chesapeake Bay estuary the larvae of some species (especially later stages) were more abundant near the bottom where net flow was upstream. Makarov (1969) found that larvae of individual decapod species were distributed differently over the Kamchatka Shelf area. He attributed this to different positions of bottom areas where larvae could settle most successfully and suggested that larvae could reach these suitable bottom areas by using currents in different water layers during their vertical movements. Adults of the shrimps Penaeus aztecus and P. duorarum inhabit oceanic waters of the Gulf of Mexico. Their postlarval stages, however, move into shallow bay nursery grounds and their occurrence in the coastal bays corresponds to periods of net inflow of water after periods of low water levels in the bays (Copeland and Truitt 1966). Swimming responses of larvae to hydrostatic pressure have also been shown to be an important factor in the utilization of currents at different depths. Naylor and Isaac (1973) have shown that the pressure responses in megalopa larvae of Callinectes sapidus and Macropipus sp. are such that would inhibit swimming in surface waters of stratified estuaries where net flow is seaward, but would promote slight upward swimming when on the bottom in deeper water which has a net flow inwards. Sulkin et al. (1980) have also demonstrated that behavioral responses of C. sapidus larvae to environmental stimuli control vertical distribution throughout larval development and play a crucial role in recruitment processes in estuaries and coastal marine areas given the characteristic circulation patterns.

Active resistance to currents has also been postulated as a mechanism for remaining near parental grounds. Makarov (1969) found that larvae of Crangon dolli and C. septemspinosa, which hatch and settle in shallow coastal waters, are very rarely encountered over great depths despite particularly strong currents near the shore. However, larvae of Paralithodes camtschatica, which also hatch in shallow water, disperse over great depths and far from shore. He postulates that in the case of Crangon larvae there is active resistance to the currents while in larvae of Paralithodes there is no such resistance.

Sandifer (1975) suggests two basic mechanisms of recruitment to decapod crustacean populations in estuaries - (1) retention of larvae that live close to the bottom where the net flow in the estuary is inward, and (2) for those larvae that inhabit surface waters in the estuary where net flow is seaward, recruitment is by immigration of juveniles and adults from outside the estuary. He further suggests that various combinations of these two mechanisms may exist among different populations. A mechanism similar to (2) above could be operating along the northeast coast of Newfoundland. It might appear that deep water in this area would be too cold for settlement of decapod larvae which originate in the near-shore area, however, larvae of C. opilio presumably settle in the deep water areas where the adults are found and one would expect the larvae of other decapod species to be capable of settling there as well. There is no real evidence, however, to suggest that this occurs.

Although those decapod species that are found in the near-shore area appear to be most abundant there, depth ranges reported by Squires (1965) indicate that they may be found in varying degrees of abundance in deeper water beyond the near-shore rocky bottom area. The relative abundance at various depths is not well documented for any decapod species in this particular area. However, of those species that occur on the "lobster grounds" only H. araneus is reported by Squires (1965) as having been taken with catches of C. opilio which were taken in depths between 80-310 m. The other species are generally restricted to shallower water.

Undoubtedly, the processes involved in recruitment to the decapod crustacean populations in the near-shore area along the northeast coast of Newfoundland are highly variable and probably very complex. It is clear, however, that decapod larvae are not simply passive current drifters and that their presence near suitable settling bottom at the end of the larval development period is the end result of well developed behavioral responses to environmental stimuli integrated with various mechanical forces operating in a given area.

ACKNOWLEDGMENTS

I am indebted to G. Dawe for providing surface assistance while the plankton collector was being operated and for sorting and counting the larvae.

REFERENCES

Chittleborough, R.G., and L.R. Thomas. 1969. Larval ecology of the western Australian marine crayfish, with notes upon other Panulirid larvae from the eastern Indian Ocean. Aust. J. Mar. Freshwat. Res. 20: 199-223.

Copeland, B.J., and M.V. Truitt. 1966. Fauna of the Aransas Pass Inlet, Texas. II. Penaeid shrimp postlarvae. Texas J. Sci. 18: 65-74.

Ennis, G.P. 1972. A diver-operated plankton collector. J. Fish. Res. Board Canada 29: 341-343.

Johnson, M.W. 1960. Production and distribution of larvae of the spiny lobster, Panulirus interruptus (Randall) with records on P. gracilis Streets. Bull. Scripps Inst. Oceanogr. 7: 413-461.

1974. On the dispersal of lobster larvae into the East Pacific Barrier (Decapoda, Palinuridea). Fish. Bull. 72: 639-647.

Knudsen, J.W. 1960. Reproduction, life-history and larval ecology of the California Xanthidae, the Pebble Crabs. Pacif. Sci. 14: 3-17.

Lebour, M.V. 1950. Notes on some larval Decapods (Crustacea) from Bermuda. Proc. Zool. Soc. London, 120: 369-379.

Makarov, R.R. 1969. Transport and distribution of decapod larvae in the plankton of the west Kamchatka Shelf. Oceanology, 9: 251-259.

Naylor, E., and M.J. Isaac. 1973. Behavioral significance of pressure responses in megalopa larvae of Callinectes sapidus and Macropipus sp. Mar. Behav. Physiol. 1: 341-350.

Phillips, B.F. 1981. The circulation of the southeastern Indian Ocean and the planktonic life of the western rock lobster. Oceanogr. Mar. Biol. Ann. Rev. 19: 11-39.

Rimmer, D.W., and B.F. Phillips. 1979. Diurnal migration and vertical distribution of phyllosoma larvae of the western rock lobster Panulirus cygnus. Mar. Biol. 54: 109-124.

Sandifer, P.A. 1973. Distribution and abundance of decapod crustacean larvae in the York River Estuary and adjacent lower Chesapeake Bay, Virginia, 1968-1969. Chesapeake Sci. 14: 235-257.

1975. The role of pelagic larvae in recruitment to populations of adult decapod crustaceans in the York Estuary and adjacent lower Chesapeake Bay, Virginia. Estuarine and Coastal Mar. Sci. 3: 269-279.

Serfling, S.A., and R.F. Ford. 1975. Ecological studies of the puerulus larval stage of the California spiny lobster, Panulirus interruptus. Fish. Bull. 73: 360-377.

Squires, H.J. 1965. Decapod crustaceans of Newfoundland, Labrador and the Canadian Eastern Arctic. Fish. Res. Bd. Canada Manusc. Rept. Series (Biol.) No. 810, 212 p.

Sulkin, S.D., W. Van Heukelem, P. Kelly, and L. Van Heukelem. 1980. The behavioral basis of larval recruitment in the crab Callinectes sapidus Rathbun: A laboratory investigation of ontogenetic changes in geotaxis and barokinesis. Biol. Bull., 159: 402-417.

Thorson, G. 1957. Bottom communities (sublittoral and shallow shelf). In Treatise on Marine Biology and Paleoecology by J.W. Hedgpeth (Editor) Vol. I. Geol. Soc. Amer. Mem. 67: 461-534.

Table 1. Summary of the occurrence of decapod crustacean larvae in plankton tows in the near-shore area at St. Chads, Bonavista Bay.

		Surface				Subsurface			
Species	Wind direction	No. tows	Prop. tows with larvae	Mean No. in tows with larvae	Range in nos. of larvae	No. tows	Prop. tows with larvae	Mean No. in tows with larvae	Range in nos. of larvae
Cancer irroratus									
	Onshore	27	.81	625.2	1-2926	31	.68	99.1	2-299
	Offshore	15	.67	11.6	2-48	18	.44	12.4	1-64
Hyas araneus									
	Onshore	27	.59	41.0	1-422	31	.35	4.1	1-19
	Offshore	15	.33	7.4	2-17	18	.06	1.0	1-
Chionoecetes opilio									
	Onshore	27	.33	16.9	1-72	31	.06	2.0	1-3
	Offshore	15	.00	0.0	-	18	.00	0.0	-
Homarus americanus									
	Onshore	27	.19	2.7	1-7	31	.00	0.0	-
	Offshore	15	.00	0.0	-	18	.00	0.0	-
Pagurus arcuatus and *P. acadianus*									
	Onshore	27	.11	1.0	1-	31	.13	4.8	3-10
	Offshore	15	.07	1.0	1-	18	.28	3.8	1-14
Eualus pusiolus									
	Onshore	27	.44	6.7	1-40	31	.35	3.6	1-11
	Offshore	15	.40	2.2	1-6	18	.17	17.0	1-46
Unidentified species									
	Onshore	27	.19	1.0	1-	31	.39	18.1	3-84
	Offshore	15	.13	1.0	1-	18	.22	3.9	1-7

Table 2. Average number of larvae per five-minute tow at different positions in a near-shore area with onshore and offshore winds. (* Number in ( ) is number of tows. These are the same for each species.)

Wind direction	Depth (m)	Distance from shore/depth (m) 2/1.5	4/3	10/6	20/9
Cancer irroratus					
Onshore	0	504.6 (7)*	525.4 (8)	991.2 (5)	151.9 (7)
	3		53.3 (9)	122.5 (4)	120.7 (6)
	6			3.0 (3)	65.6 (5)
	9				12.5 (4)
Offshore	0	22.0 (1)	5.2 (5)	14.4 (4)	2.0 (5)
	3		0.6 (5)	10.2 (3)	16.3 (4)
	6			1.0 (1)	0.0 (3)
					0.0 (2)
Hyas araneus					
Onshore	0	9.6	54.0	8.2	16.6
	3		2.2	1.0	1.7
	6			0.0	2.2
	9				0.0
Offshore	0	0.0	1.0	1.0	5.6
	3		0.2	0.0	0.0
	6			0.0	0.0
	9				0.0

...Cont'd.

Table 2. (Cont'd.)

Wind direction	Depth (m)	Distance from shore/depth (m) 2/1.5	4/3	10/6	20/9
Chionoecetes opilio					
Onshore	0	3.1	9.1	8.4	2.1
	3		0.3	0.3	0.0
	6			0.0	0.0
	9				0.0
Offshore	0	0.0	0.0	0.0	0.0
	3		0.0	0.0	0.0
	6			0.0	0.0
	9				0.0
Homarus americanus					
Onshore	0	0.1	0.4	1.5	0.3
	3		0.0	0.0	0.0
	6			0.0	0.0
	9				0.0
Offshore	0	0.0	0.0	0.0	0.0
	3		0.0	0.0	0.0
	6			0.0	0.0
	9				0.0

...Cont'd.

Table 2. (Cont'd.)

Wind direction	Depth (m)	Distance from shore/depth (m) 2/1.5	4/3	10/6	20/9
Pagurus arcuatus and *P. acadianus*					
Onshore	0	0.0	0.3	0.0	0.1
	3		0.0	0.0	0.5
	6			0.0	1.2
	9				2.5
Offshore	0	0.0	0.2	0.0	0.0
	3		0.2	0.3	0.3
	6			0.0	0.7
	9				7.0
Eualus pusiolus					
Onshore	0	6.0	0.4	5.4	0.3
	3		0.4	3.5	1.0
	6			1.0	2.2
	9				0.3
Offshore	0	1.0	0.8	1.8	0.2
	3		0.2	1.3	11.5
	6			0.0	0.0
	9				0.0
Unidentified shrimp					
Onshore	0	0.0	0.3	0.4	0.0
	3		1.8	18.5	0.7
	6			28.0	1.8
	9				7.3
Offshore	0	1.0	0.0	0.3	0.0
	3		0.0	1.5	1.8
	6			0.0	0.0
	9				2.0

Table 3. Average number of *Cancer irroratus* megalopae per five-minute tow at different positions in a near-shore area with onshore and offshore winds. Only those sets of tows in which megalopae were taken are included. (* Number in ( ) is number of tows.)

Wind direciton	Depth (m)	Distance from shore/depth (m) <2/1.5	4/3	10/6
Onshore	0	1.5 (2)*	74.5 (2)	88.7 (3)
	3		1.5 (2)	1.3 (3)
	6			0.0 (1)
Offshore	0	0.0 (3)	10.0 (3)	4.9 (4)
	3		0.0 (2)	0.5 (4)
	6			0.0 (1)

Table 4. Average and range in number per five-minute tow of various larval stages for each species.

	Stage I	Stage II	Stage III	Stage IV	Stage V	Megalopa
Cancer irroratus						
Average No.	187.3*		2.1	1.4		21.2
Range	1-2926		1-9	1-2		1-110
No. tows**	150		7	4		26
Hyas araneus						
Average No.	15.9	2.5				
Range	1-419	1-7				
No. tows	69	6				
Chionoecetes opilio						
Average No.	9.4					
Range	1-72					
No. tows	19					
Homarus americanus						
Average No.	2.6					
Range	1-7					
No. tows	5					
Pagurus arcuatus and *P. acadianus*						
Averge No.	3.7			1.5	1	1
Range	1-14			1.2		
No. tows	27			2	1	3
Eualus pusiolus						
Average No.	7.5	1	1		1.5	1.4
Range	1-46				1-2	1-3
No. tows	72	3	1		2	7
Unidentified shrimp						
Average No.	4.7	4.3	3.6	2.3		
Range	1-32	1-28	1-20	1-15		
No. tows	29	28	24	28		

* For *C. irroratus* stages I and II were not separated.
** No. tows in which stage was taken.

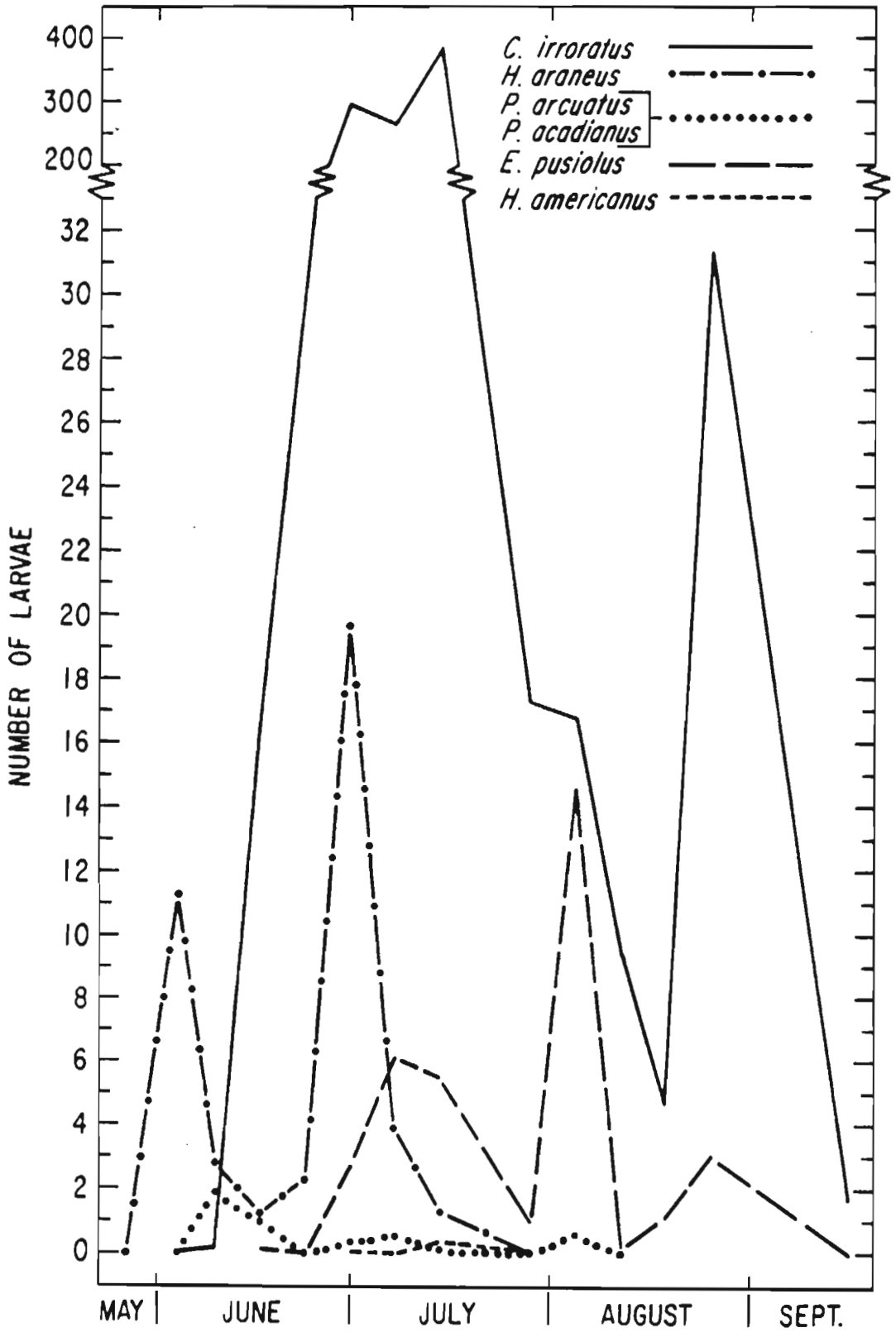

Fig. 1. Average number of stage I larvae per five-minute tow at weekly intervals from May to September for different species (for C. irroratus Stages I and II were not separated). Only those tows in which larvae were taken are included.

APPENDIX

Set 1 - July 3, moderate onshore wind, overcast, moderate surge along shore.

Set 2 - July 13, moderate onshore wind, overcast, no surge.

Set 3 - July 14, light onshore wind, overcast, no surge.

Set 4 - June 25, light to moderate onshore wind, overcast, slight surge along shore.

Set 5 - June 29, moderate onshore wind, cloudy with sunny intervals, heavy surge along shore.

Set 6 - July 2, moderate onshore wind, overcast and light rain, heavy surge along shore.

Set 7 - June 16, moderate offshore wind, sunny and clear, light surge along shore.

Set 8 - July 16, moderate offshore wind, overcast, light surge along shore.

Set 9 - August 9, strong offshore wind, sunny and clear, no surge.

Set 10 - July 6, no wind, overcast with light rain, light surge along shore.

Set 11 - July 1, no wind, sunny with cloudy periods, light surge along shore.

Set 12 - July 12, no wind, overcast with light rain, no surge.

Set 13 - June 7, light offshore wind, overcast with light rain, moderate surge along shore.

Set 14 - June 8, moderate onshore wind, overcast with light rain, light surge along shore.