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Discrimination of Atlantic Snow Crab, *Chionoecetes opilio*, Populations: a Problem of Management Application

by

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Adult snow crabs from the western Gulf of St. Lawrence, eastern Cape Breton Island, western Cape Breton Island and northeastern Newfoundland were analyzed for morphometric, meristic and electrophoretic characteristics. The morphometric and meristic analyses infer that crabs from all four sample areas are morphologically distinct. The electrophoretic study also infers that Newfoundland and Gulf of St. Lawrence snow crabs differ genetically from each other and from Cape Breton Island samples; eastern and western Cape Breton Island snow crabs appear genetically identical.

Despite the fact that all Cape Breton Island snow crab appear part of the same population, comparisons (1978-81) of commercial biomass between the Gulf and Atlantic coasts of the Island indicate widely different degrees of resilience to exploitation. The fishery on the Atlantic coast has rapidly collapsed in the absence of significant biomass additions. In contrast, on the Gulf coast larger recruitment levels relative to catches have offset declines in commercial biomass and catch rates.

The Cape Breton Island snow crab experience highlights the fact that the "population" alone is not necessarily a useful management tool. Populations may be more usefully sub-divided in stock management units which reflect intra-population factors such as growth and recruitment patterns.

STOCK DISCRIMINATION SYMPOSIUM

Introduction

Since its inception in the mid to late 1960's, the snow crab, Chionoecetes opilio, fishery has increased steadily in importance to its present position as the most valuable crab species fished in Canadian waters and the sixth most valuable fishery in Atlantic Canada (Elner 1982a).

In recent years the decreasing size of crabs caught and the collapse of the fishery in some areas (Elner 1982b) indicate that the virgin biomass of snow crabs has been essentially extinguished and the fishery is now largely recruitment-based. In response to this trend, the present study was initiated to elucidate stock structure and probable recruitment mechanisms for Atlantic snow crabs. Such knowledge was deemed essential for the development of an optimum snow crab management strategy.

Methods and Materials

Mature male and female snow crabs were collected for morphometric and meristic analyses from commercial fishing grounds off St. John's, Newfoundland; Pleasant Bay and Cheticamp, Nova Scotia; Gabarus, Nova Scotia, and Rivière-au-Tonnerre, Quebec (Fig. 1). Snow crabs were preserved in 10% formalin-seawater and transported to St. Andrews, New Brunswick, for processing. The sex, 42 morphometric measurements and 8 meristic counts were recorded for each crab. Morphometric and meristic data were subjected to an SPSS discriminant function analysis to obtain an index of the uniqueness of each stock examined.

Snow crabs for electrophoretic analyses were obtained from commercial fishing grounds off Gabarus, Nova Scotia; Pleasant Bay, Nova Scotia; Forestville, Quebec, and Port de Grave, Newfoundland (Fig. 1). The right chelipeds of live, hard-shelled males (>95 mm carapace width) were removed and preserved in dry ice. The samples were stored in dry ice or in freezers at < -35°C until being transported to the University of Windsor, Windsor, Ontario, where a disc polyacrylamide electrophoresis survey of 10 enzyme systems was made for merus and propodus muscles from each sample cheliped (Table 1).

Results

Using all 50 morphometric and meristic variables, the proportion of both males and females properly classified by discriminant function analysis (i.e., their predicted group membership coinciding with the group from which they originate) exceeds 83% for all areas (Table 2). A higher percentage of females than males was properly classified for areas other than Pleasant Bay-

Cheticamp (Table 2). Newfoundland exceeds the other areas in the percentage of both males and females properly classified (Table 2). A distinct pattern of misclassification (i.e., the assignment of individuals to groups other than the ones from which they originated) does not appear to exist (Fig. 2).

A comparison of the percentage of individuals properly classified versus the number of variables used for classification in the discriminant function analysis (Fig. 3) indicates that the use of 12 to 15 discriminating variables would provide at least 70% proper classification and be logistically preferable to the 50 morphometrics and meristics used in this study.

Results from the electrophoretic study were confounded by enzyme breakdown due to improper handling of the samples during transport. Of those enzymes which resolved well (LDH, MDH, fumerase, G-6-PDH, and esterase), only esterase exhibited polymorphisms. Eight phenotypes (banding patterns) were observed. Only the Newfoundland snow crabs exhibited all 8 esterase phenotypes (Table 3). Six phenotypes were observed in the Forestville snow crabs and only 3 phenotypes were present in the Gabarus and Pleasant Bay samples (Table 3). A chi-squared comparison of phenotype frequencies between areas (Table 4) shows that Gabarus and Pleasant Bay do not sifnificantly differ from each other while both Newfoundland and Forestville samples are significantly different from each of the other samples.

Discussion

The interpretation of the morphometric, meristic and electrophoretic results in terms of delineating stocks depends on the implied definition of "stock". If a "stock" is considered an intra-specific group of individuals which exhibit specific phenotypic attributes in response to environmental and/or genetic factors, then results of the morphometric and meristic study presented in this paper would indicate that the four snow crab areas sampled represent four distinct stocks. As discussed by Booke (1981), the genetic and environmental effects on phenotypic characteristics are often difficult to distinguish. The results of the present study are a case in point: As the physical characteristics of all four sample areas are similar and temporally homogeneous, we assumed that the majority of phenotypic variability observed would be due to genetic dissimilarities. Our assumption failed to consider the effect of the environment on early life history stages. We realized this failure when we attempted to explain why a higher percentage of females, compared to males, was properly classified. Females have a terminal molt to maturity and, thus, do not exhibit morphological changes in response to their adult environment. Therefore, we hypothesized that morphological differentiation in response to environmental factors in snow crabs occurs during the juvenile stages when the crabs live in a more heterogeneous environment. As the crabs grow larger and move to their more homogeneous adult environment they tend to converge in their morphological attributes. This convergence is cut short in females due to their terminal molt but extends on through the life of adult males. A preliminary analysis of the morphometric and meristic data from this study supports our hypothesis: Crabs were arranged by sex into arbitrarily delineated small (males $\leq$80 mm carapace width, females $\leq$ 60 mm carapace width), medium (males 80.1-100 mm carapace width; females 60.1-70 mm carapace width), and large (males >100 mm carapace width; females >70 mm carapace width) size groups and then each size group was subjected to a discriminant function analysis of their morphometric and meristic attributes. The percentage properly classified according to area in small, medium and large size groups was 87.9%, 79.4% and 75.2%, respectively, for males and 93.3%, 69.1% and 68.1%, respectively, for females. These results indicate that small crabs from different areas are more morphologically distinct than large crabs from those same areas, as the above hypothesis proposes.

Several authors (Harroll 1981; Booke 1981; Kutkuhn 1981) imply that for the formation and maintenance of stocks "a moderately high degree of reproductive isolation is necessary" (Harroll 1981). The results of electrophoretic studies are much used for inferring genetic similarities or differences between both inter- and intraspecific populations. The electrophoretic results in our study support those of the morphometrics and meristics by inferring that the snow crabs from Newfoundland and the western Gulf of St. Lawrence (Forestville and Anticosti) differ significantly from each other and from those of Pleasant Bay-Cheticamp and Gabarus. However, the electrophoretic results conflict with the morphometric and meristic results by indicating that Gabarus and Pleasant Bay-Cheticamp snow crabs do not significantly differ from each other and represent one genetic stock.

If genetic characteristics of samples (as opposed to phenotypic characteristics) are accepted as the basis for delineating stocks, then a reason for the genetic characteristics should be postulated. All of the snow crab areas sampled are geographically separated, therefore, the lack of interbreeding between adults from different sample areas provides an explanation for the inferred genotypic differences. Why then do the Pleasant Bay-Cheticamp and Gabarus populations appear genetically identical? The answer may lie in the exchange of pelagic larvae. With the pelagic duration of larval snow crabs being 60-70 days (Kon 1970; Davidson, unpublished data) and given typical summer surface circulation patterns (Fig. 4), it is feasible for genetic exchange through larval recruitment to occur between all maritime snow crab grounds. The magnitude of larval exchange between areas would be affected by oceanographic patterns and should be directly proportional to the distance between areas, the velocity of surface currents and larval duration. East and west Cape Breton snow crab grounds are close geographically (Fig. 1) with strong currents running between them (Fig. 4) thus, a large amount of larval recruitment to the east Cape Breton snow crab grounds conceivably originates from snow crab grounds off western Cape Breton.

Given the stock definition is frequently undertaken to define management units, we can review the applicability of the 'single-stock-management-unit' concept by comparing the history of two areas within the Cape Breton Island (genetic) stock: Fortuitously, for the illustrative purposes of our paper since 1978, Cape Breton Island fishing grounds off Pleasant Bay and Cheticamp (snow crab area 1) and Gabarus (snow crab area 5) (Fig. 5) have been recipients of the same management strategy. Management's goal has been to develop the Cape Breton Island fishery as a stable, supplementary fishery with a large number of participants. Consequently, total allowable catch (TAC) restrictions enforced in area 1 and area 5 have been based on a strategy of permitting only the harvest of biomass equivalent to the calculated growth and a recruitment additions for the previous year, in an attempt to maintain a large stable stock. Intuitively, areas 1 and 5 should have responded similarly to management's efforts. However, within four fishing seasons catch rates and the commercial biomass in area 5 has collapsed (Fig. 6, 7). In contrast, although the exploitation in area 1 has been continuous since 1966, the catch rates and commercial biomass have remained relatively stable since monitoring began in 1978 (Fig. 8, 9). The substantial differences in historical landings between areas 1 and 5 appear more remarkable given that the areas are of approximately equal size (2750 km^2 vs 2059 km^2), have similar numbers of fishermen (27 vs 26) and are separated by less than 160 km of landmass. Furthermore, with the existing minimum legal carapace width of 95 mm being above the maximum size attained by female snow crabs, the number of females in the Atlantic is assumed to equal pre-fishery levels and, hence, decreases in egg production are unlikely to be a factor in the collapse.

Evidence from stock assessments over 4 years indicates that area 5 and the remaining east coast snow crab grounds are unproductive in terms of growth and recruitment. Possibly, the eastern areas, being at the southern edge of known commercial snow crab concentrations in the Atlantic, represent marginal grounds in terms of habitat. Thus, although comparisons of biomass, growth and recruitment levels, as well as catch rates and size frequencies for area 5 reveal apparent recruitment failures, it may be that the situation represents the normal pattern of growth. Thus, the eastern Cape Breton Island snow crab grounds were probably built up over time through trickles of movement, growth, and recruitment. Such a scenario would account for the initially high catch rates and landings on the grounds, the lack of resilience of the stocks to exploitation, and the subsequent devastation of biomass and catch rates after only a few fishing seasons.

In contrast to the east coast, the management by 'stable-stock' policy appears to have succeeded in area 1 on the west coast. The magnitude of overall annual biomass additions in area 1, although variable in periodicity, have appeared relatively large and consistent since 1978. This consistency, despite high exploitation rates of 47-64%, has conferred resilience to the area 1 stock and has facilitated management. Given that stability has been achieved in area 1 at the expense of curbing effort and landings, the long-term sustainable yield for the fishery appears to be approximately 1,000 MT per annum.

Between 1978 and 1980 biological advice for a cautious approach to exploitation of snow crab stocks was ignored, due mainly to the initially high catch rates. Now, the biological problems are compounded by excessive potential effort threatening future prospects for recovery in the fishery. In 1982, management acknowledged that the general strategy for snow crab exploitation in Atlantic Canada was not applicable to eastern areas of Cape Breton Island. As the reproductive potential of the resource is protected by minimum size regulations, management has dropped catch controls for the east coast areas and, from 1982 onwards, plans to allow fishermen to exploit snow crabs on a largely opportunistic basis.

The Cape Breton Island experience shows that the stock _per se_, as defined by genetic and/or phenotypic characteristics, is not necessarily a meaningful management unit. Stocks may be more usefully sub-divided into management units which reflect intra-stock factors such as growth and recruitment patterns.

In summary, unique phenotypic and/or genotypic characteristics of intraspecific groups of individuals may be useful in the delineation of stocks, but should not be accepted as a basis for management strategies until the biotic and abiotic factors governing these characteristics are elucidated.

Acknowledgements

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Table 1. Enzymes surveyed during electrophoretic examination of cheliped muscles from snow crab.

Enzyme	Abbreviation
α-Esterases	--
Glucose-6-phosphate dehydrogenase	G-6-PDH
Glutamic oxalacetic transaminase	GOT
Phosphoglucoisomerase	PGI
Lactic dehydrogenase	LDH
Malate dehydrogenase	MDH
Leucine amino peptidase	LAP
Phosphoglucomutase	PGM
Fumerase	--
Xanthine dehydrogenase	XDH

Table 2. Discriminant function classification results for Snow Crabs from four Maritime populations.

			Predicted Group Membership							
	No. of Cases		Newfoundland		Pleasant Bay-Cheticamp		Gabarus		Anticosti	
Actual Group	males	females	males	females	males	females	males	females	males	females
Newfoundland	50	51	90.0%	94.1%	0.0%	2.0%	2.0%	0.0%	8.0%	3.9%
Pleasant Bay-Cheticamp	121	119	3.3%	4.2%	87.6%	86.6%	7.4%	4.2%	1.7%	5.0%
Gabarus	101	98	0.0%	2.0%	5.9%	4.1%	83.2%	90.8%	10.9%	3.1%
Anticosti	174	99	4.0%	3.0%	0.6%	3.0%	11.5%	3.0%	83.9%	90.9%

Females from all areas correctly classified - 89.9%

Males from all areas correctly classified - 85.4%

Table 3. Frequency of esterase phenotypes for four sample population of snow crabs.

Phenotypes	Sample Population			
	Newfoundland	Forestville	Gabarus	Pleasant Bay
MF	30 (48.4%)	11 (20.0%)	0 (-----)	0 (-----)
S_3 MF	5 (8.1%)	33 (60.0%)	60 (96.8%)	54 (93.1%)
S_2 S_3 MF	4 (6.4%)	5 (9.2%)	1 (1.6%)	3 (5.2%)
S_1 S_2 S_3 MF	11 (17.7%)	3 (5.4%)	0 (-----)	0 (-----)
S_1 S_2 MF	6 (9.8%)	1 (1.8%)	0 (-----)	0 (-----)
S_1 MF	1 (1.6%)	0 (-----)	0 (-----)	0 (-----)
S_2 MF	4 (6.4%)	2 (3.7%)	0 (-----)	0 (-----)
S_1 S_3 MF	1 (1.6%)	0 (-----)	1 (1.6%)	1 (1.7%)

Table 4. Chi-squared comparison of esterase phenotype frequencies.

	Forestville		Pleasant Bay		Gabarus	
Newfoundland	40.8	14.1	92.8	14.1	100.3	14.1
Anticosti	--	--	23.5	12.6	28.2	12.6
Pleasant Bay	--	--	--	--	1.2	5.99

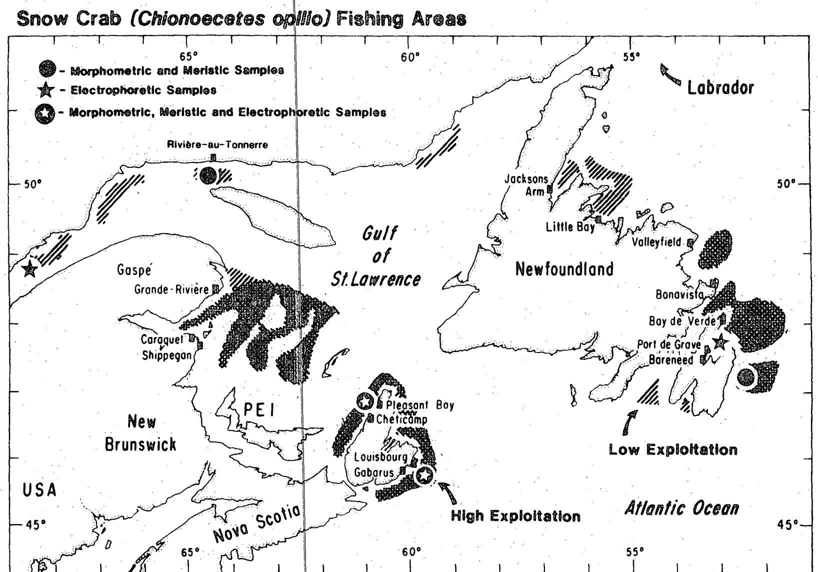

Fig. 1. Maritime Snow Crab (<u>Chionoecetes</u> <u>opilio</u>) Fishing Areas and Sample Sites.

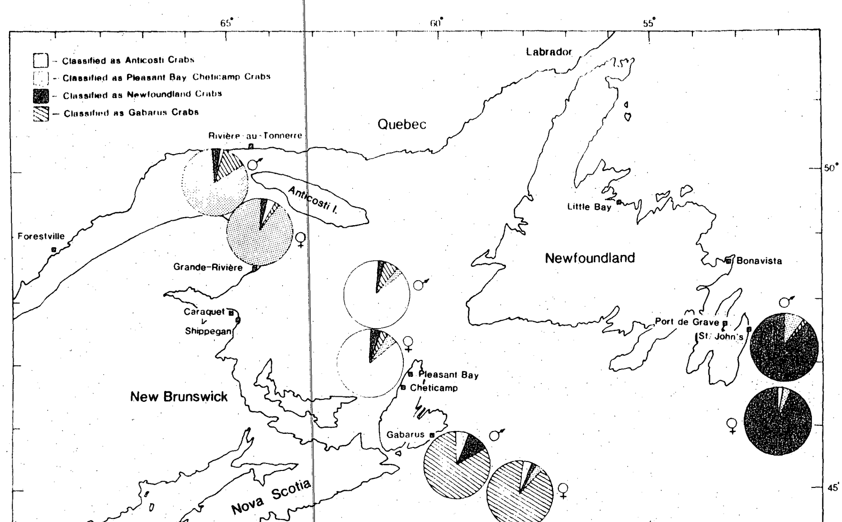

Fig. 2. Classification Results for Male and Female Snow Crabs from Four Maritime Populations.

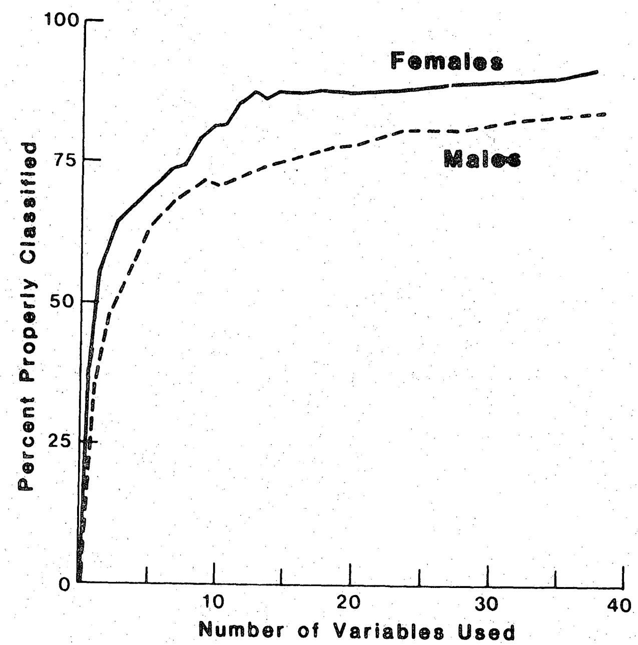

Fig. 3. Discriminant Function Analysis of Snow Crab Morphometrics and Meristics - Percent Properly Classified versus the Number of Variables Used.

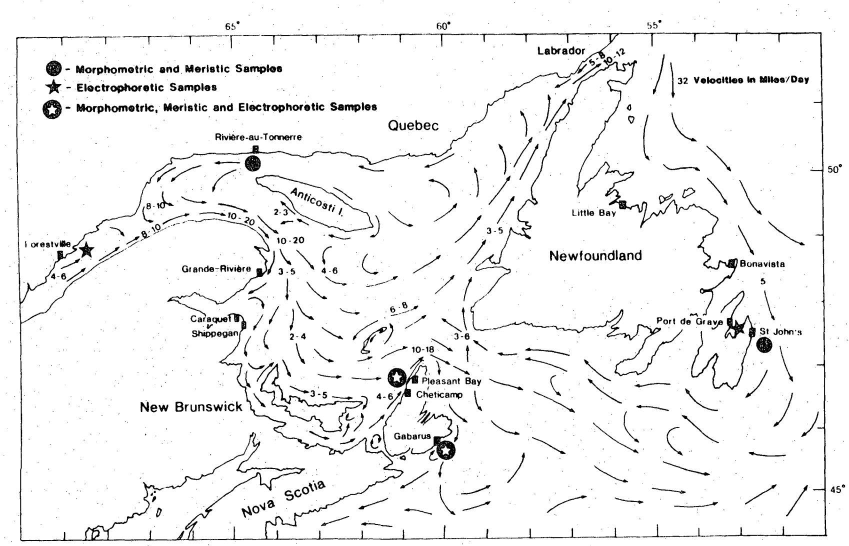

Fig. 4. Typical and Extrapolated Maritime Summer Surface Circulation Patterns in Relation to Snow Crab Sample Sites (after Trites 1970; Bumpus and Lauzier 1965; Sutcliffe et al. 1976; Hachey 1961; Kudlo and Burmakin 1972).

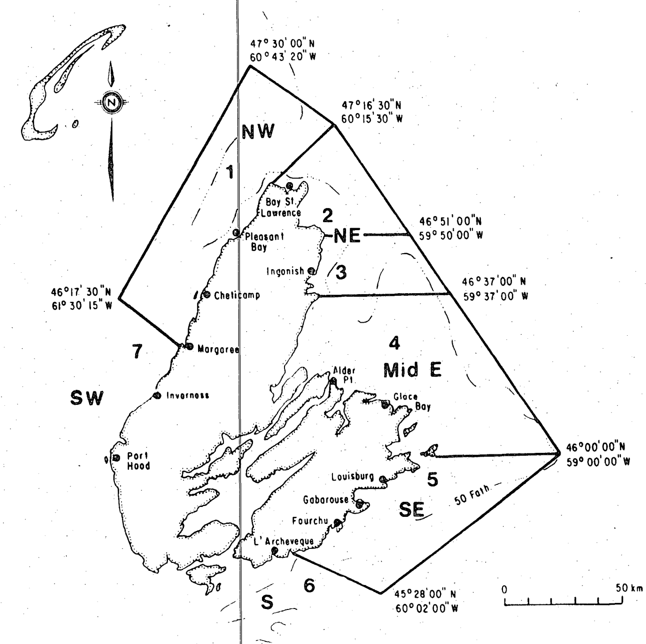

Fig. 5. Snow Crab Management Areas Around Cape Breton Island.

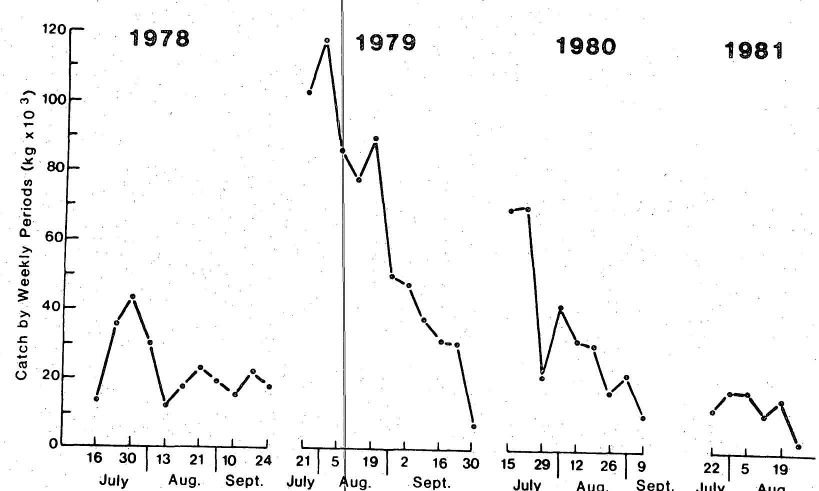

Fig. 6. Trends in Catch by Weekly Period for Area 5, SE Cape Breton Island, 1978-81.

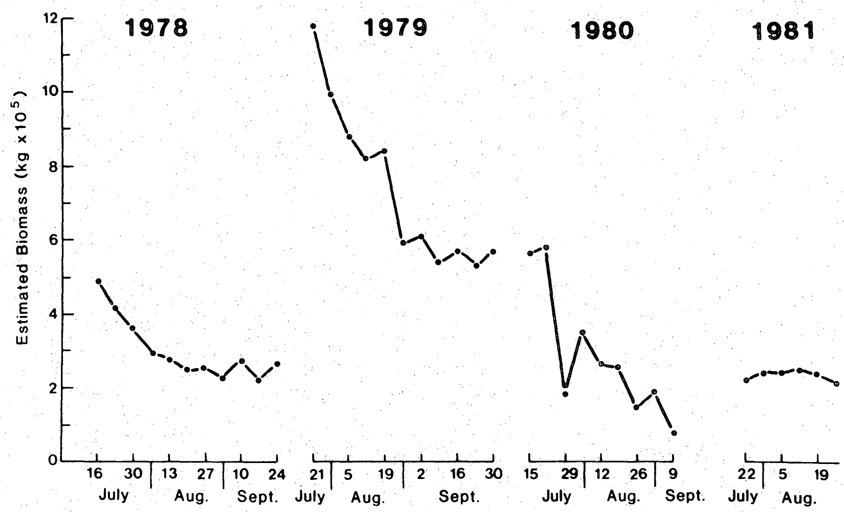

Fig. 7. Trends in Commercial Snow Crab Biomass for Area 5, SE Cape Breton, 1978-81.

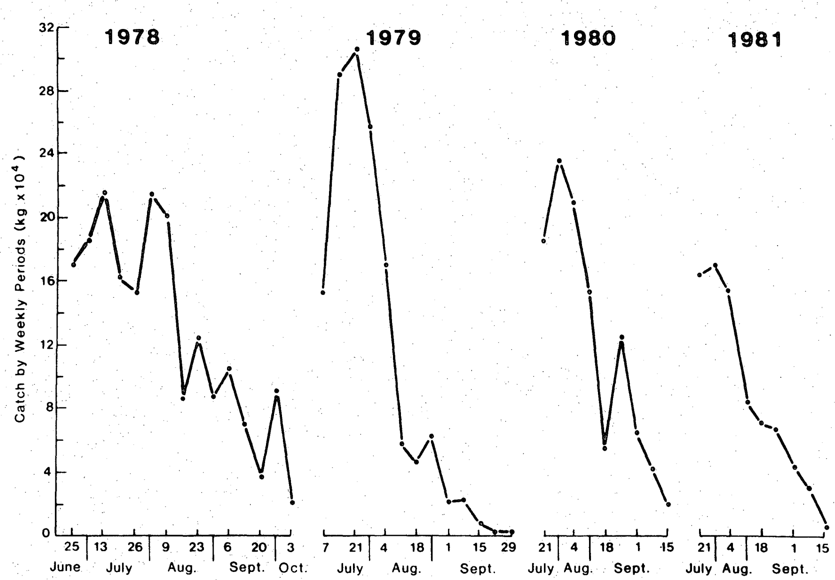

Fig. 8. Trends in Catch by Weekly Period for Area 1, NW Cape Breton, 1978-81.

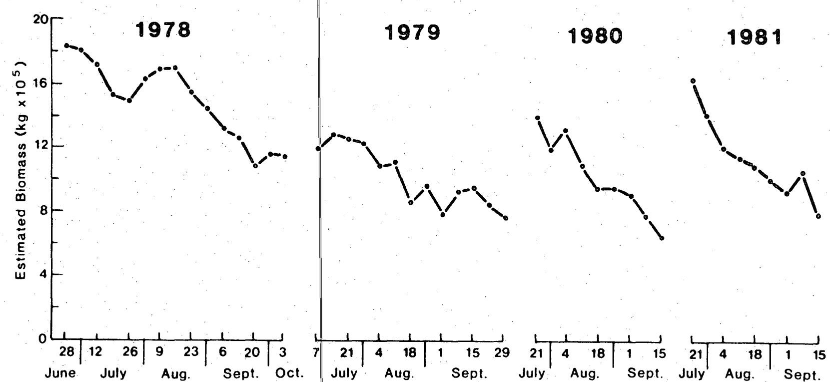

Fig. 9. Trends in Commercial Snow Crab Biomass for Area 1, NW Cape Breton, 1978-81.