DISTRIBUTION, POPULATION OVERLAP, AND MORPHOLOGICAL SHELL VARIATION IN *MYTILUS CALIFORNIANUS* CONRAD AND *MYTILUS EDULIS* LINNAEUS ON THE WEST COAST OF VANCOUVER ISLAND

by

William M. Blaylock

B.SC., California Polytechnic State University, 1975

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF

MASTER OF SCIENCE

in the Department

of

Biological Sciences

SIMON FRASER UNIVERSITY

August 1980

PARTIAL COPYRIGHT LICENSE

Title of Thesis/~~Project/Extended Essay~~

Distribution, Population Overlap, and Morphological Shell Variation in *Mytilus californianus* Conrad and *Mytilus edulis* Linnaeus on the west coast of Vancouver Island

Author: ______________________

(signature)

William M. Blaylock

(name)

Nov. 27, 1980

(date)

Approval

Name: William M. Blaylock

Degree: Master of Science

Title of Thesis: Distributuion, Population Overlap, and Morphological Shell Variation in *Mytilus californianus* Conrad and *Mytilus edulis* Linnaeus on the west coast of Vancouver Island

Examining Committee:

Chairman: Dr. Michael J. Smith

Dr. P.V. Fankboner, Senior Supervisor

Dr. E. B. Hartwick

Dr. L. D. Druehl

Dr. N.A.M. Verbeek, Public Examiner
Associate Professor
Department of Biological Sciences
Simon Fraser University

Date approved 18 November 1980

Abstract

A study was initiated to determine the distribution and population overlap of two mussel species, *Mytilus californianus* Conrad and *Mytilus edulis* Linnaeus, in Clayoquot and Barkley Sounds on the west coast of Vancouver Island, British Columbia and to identify external shell characters that can be used to separate *Mytilus californianus* and *Mytilus edulis* in these areas. Distribution and overlap patterns were charted by examining all growths of mussels along a continuous stretch of shoreline in the study area. In order to analyze the shell morphology, samples (n=400) of *Mytilus californianus* and *Mytilus edulis* were collected from sites considered typical for each species within Barkley Sound. A series of 13 measurements of external shell morphology were made on each shell and this data was analyzed using multivariate analysis of variance, principal components analysis, and discriminant analysis. Results of these tests were then compared with similar tests run on samples (n=25) of *Mytilus californianus* and *Mytilus edulis* from overlapping and atypical habitats to determine the degree of variability in shell morphology and to identify shell characters that proved to be reliable in classification. The results can be summarized as follows:

1. Population overlap between *Mytilus californianus* and *Mytilus edulis* is widespread within the study area, with *Mytilus edulis* occupying a wider range

of habitat types than previously reported.

2. Overlapping populations show some similarity in component scores within a sampled habitat but can vary considerably between habitats.
3. A combination of four shell characters accurately discriminates between *Mytilus californianus* and *Mytilus edulis* in all habitats encountered.
4. *Mytilus californianus* and *Mytilus edulis* show some degree of shell convergence in areas of population overlap.

Acknowledgements

I would like to acknowledge the assistance and advice of my Senior Supervisor, Dr. Peter Fankboner, and the other members of my Supervisory Committee, Dr. Brian Hartwick and Dr. Louis Druehl, in the research and writing of this thesis. I would also like to thank my wife, Jane Laskowski Blaylock, for all her help and patience.

Table of Contents

List of Tables

List of Figures

Introduction

Marine molluscs frequently display significant intraspecific variation in external shell morphology. For instance, Russell (1972) reports that the mean number of ribs on the exterior of the shells of the bivalves *Cardium edule* Linnaeus and *Cardium glaucum* Brugeiér will vary according to habitat. A similar situation exists in the degree of shell ornamentation, or sculpturing, of the gastropod *Nucella lapillus* Linnaeus where specimens collected from different habitats in the Bristol Channel (Crothers, 1974) and Lough Ine (Kitching, et. al., 1966) show patterns of shell sculpturing that are consistent within habitats and highly variable between habitats. Physical factors of the environment are generally regarded as the primary cause of geographic morphologic variation within a molluscan species (Purchon, 1939), and it has been suggested that among these physical factors, exposure to wave shock will have the most profound effect on molluscan external shell morphology (Fox and Coe, 1943; Fairbridge, 1953; Abbott and Jensen, 1967; Seed, 1968; Russell, 1972).

Within the large genus *Mytilus*, *Mytilus californianus* Conrad, the sea mussel, and *Mytilus edulis* Linnaeus, the bay mussel, occur commonly along the Pacific Coast of North America from Baja California to Alaska (Ricketts, et. al., 1968) and are the two mussels most commonly found on the British Columbia coastline (Quayle, 1960). Both *Mytilus* *californianus* and *Mytilus edulis* are known to have a highly variable external shell morphology (Fox and Coe, 1943; Seed, 1968) and these differences appear to be environmentally induced (Harger, 1970a, 1970b).

The habitats occupied by the two species are generally considered to be quite distinct; *Mytilus californianus* is associated with open coast situations while *Mytilus edulis* typically inhabits protected waters (Quayle, 1960). My initial observations showed that on the west coast of Vancouver Island populations of *Mytilus californianus* and *Mytilus edulis* frequently overlap in several different types of habitats. Vancouver Island's western coastline is remarkably variable (Fig. 1); its 448 km length includes five major sounds and over twenty-five inlets (Pickard, 1963) plus numerous small islands (Anon., 1962). This coastal configuration results in numerous situations where areas of exposed outer coast are immediately adjacent to protected coast (Pickard, 1963). As a consequence, the west coast of Vancouver Island exhibits a unique, extensive intertidal region possessing a mixture of habitats which apparently allows the existence of both separate and mixed populations of *Mytilus californianus* and *Mytilus edulis*.

In this regard, I proposed to examine three questions. First, what is the distributional pattern of *Mytilus californianus* and *Mytilus edulis* at selected sites on the west coast of Vancouver Island and to what extent do the populations overlap? Second, are there external shell characters that can be used for species identification in all habitats encountered? Third, do the shell morphologies of Mytilus californianus and Mytilus edulis show any signs of convergence in habitats where populations overlap?

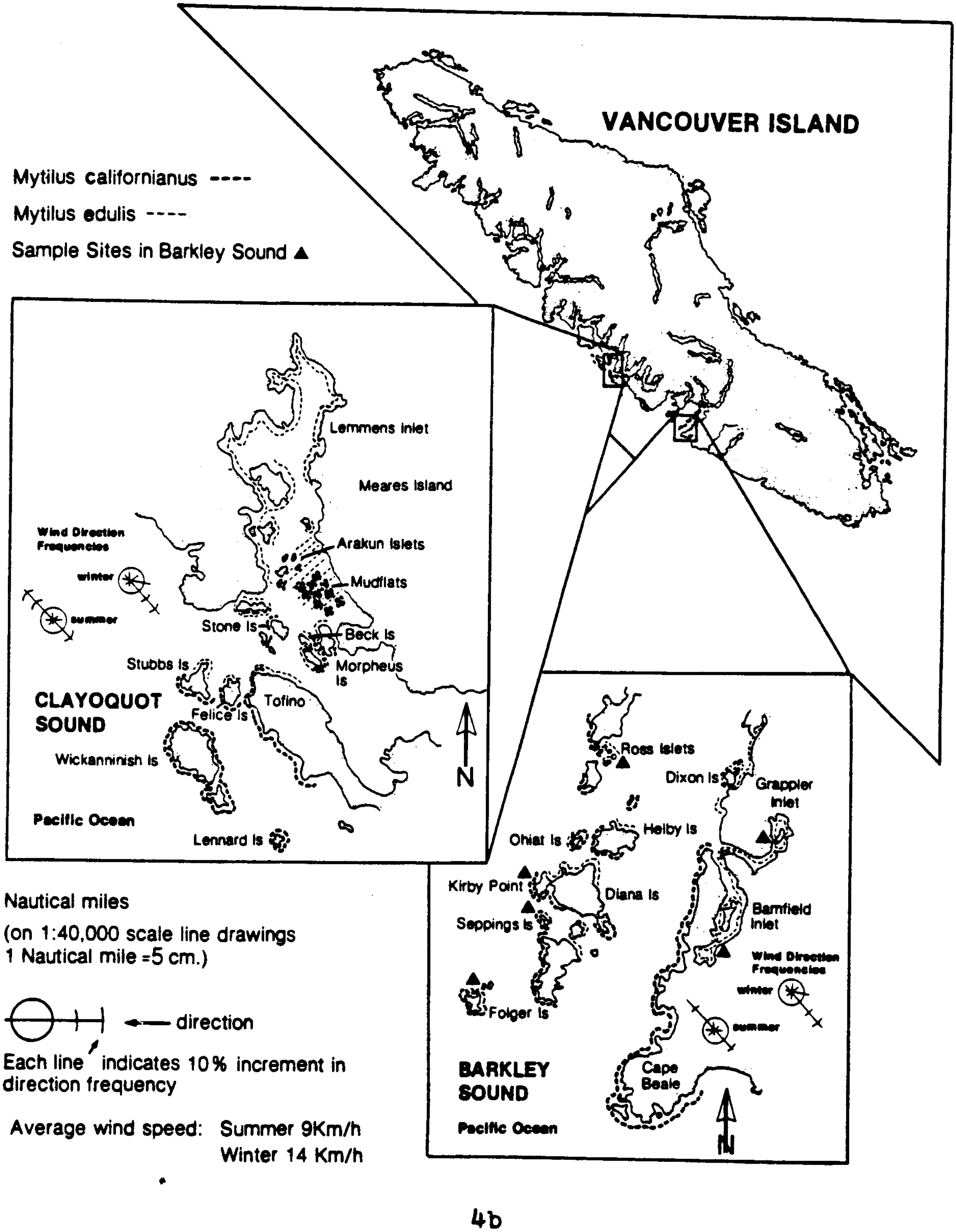
Materials and Methods

The region of Clayoquot Sound near the town of Tofino (Fig. 1) and the portion of Barkley Sound containing Trevor Channel near Bamfield (Fig. 1) were selected to map the distribution of Mytilus californianus and Mytilus edulis because they offer a wide range of habitat types.

The initial distributional survey was done in Clayoquot Sound during January to April, 1976. The second distributional survey and subsequent sampling for morphological variation was carried out from September to December, 1976, in Barkley Sound. Barkley Sound was chosen for the bulk of the experimental work because over a relatively small geographic area within it, several different habitats were encountered by Mytilus californianus and Mytilus edulis.

Identical methods were used to survey the distribution of Mytilus californianus and Mytilus edulis in Clayoquot Sound and Barkley Sound. The shoreline in each area was followed and checked for aggregations of mussels. All mussel beds were thoroughly searched by walking through the beds and noting which species were present. The geographic location of mussel beds of single and mixed species

Figure 1. Study Area, Sample Sites, and Distribution of *Mytilus californianus* and *Mytilus edulis* in Clayoquot Sound and Barkley Sound


VANCOUVER ISLAND
Mytilus californianus ----
Mytilus edulis ----
Sample Sites in Barkley Sound ▲
Lemmens Inlet
Meares Island
Wind Direction Frequencies
winter
summer
Arakun Islets
Mudflats
Stone Is
Beck Is
Stubbs Is
Morpheus Is
CLAYOQUOT SOUND
Tofino
Felice Is
Wickanninish Is
N
Pacific Ocean
Lennard Is
Ross Islets
Dixon Is
Grappler Inlet
Helby Is
Ohiat Is
Kirby Point
Diana Is
Seppings Is
Bamfield Inlet
Wind Direction Frequencies
winter
summer
Folger Is
BARKLEY SOUND
Cape Beale
Pacific Ocean
N
Nautical miles
(on 1:40,000 scale line drawings
1 Nautical mile =5 cm.)
direction
Each line indicates 10% increment in direction frequency
Average wind speed: Summer 9Km/h
Winter 14 Km/h

composition was recorded on maps for the area and this information was used to develop a distributional map (Fig. 1) for both species in the study area.

Shell Characters Used for Identification

Since the taxonomy of *Mytilus californianus* and *Mytilus edulis* is almost entirely based on shell features, information concerning shell morphological variation will aid in correct identification. Given overlapping populations of mussels, a set of shell characters that are readily measurable in field use and that do discriminate accurately between *Mytilus californianus* and *Mytilus edulis* is desirable.

A knowledge of the typical shell morphology for *Mytilus californianus* and *Mytilus edulis* was needed before studying morphological variation. Samples of *Mytilus californianus* were collected from a wave-exposed rock shelf habitat on Seppings Island (Fig. 1) and samples of *Mytilus edulis* were collected from the smooth boulders in a protected bay in Bamfield Inlet (Fig. 1), both locales are considered typical for the species found there (Quayle, 1960). At both sites the mussels were growing as a monolayer and both the density and the tidal height of the two populations were roughly equal. Samples were obtained by randomly placing a $\frac{1}{2}m^2$ quadrat in the mussel bed and removing all mussels within the quadrat. Random placement was achieved by throwing the quadrat over my shoulder into the mussel bed. A specific number of mussels was then selected at random from this large group to serve as the samples for statistical analysis of shell morphology. Four hundred mussels of each species were collected and the shell valves separated into four size classes (100 mussels per size class): 7-16 mm, 16-25 mm, 25-35 mm, and 35-50mm. Shell valves were marked on the inner nacreous layer to indicate the collection site.

To study the effects of different habitat types on shell morphology and the possibility of convergence of shell form in regions of overlap, additional samples of *Mytilus californianus* and *Mytilus edulis* were collected from various sites within Barkley Sound (Fig. 1). For instance, samples (n=25 mussels) were taken in regions of species overlap and where the two species were in physical contact with one another: Dixon Island, Diana Island, Folger Island, and the lee side of Seppings Island. These sample sites were chosen on the basis of their orientation to wave splash. The amount of exposure at each site was determined qualitatively based on the orientation of the site to the open sea and direct observation of the amount of wave splash each site received. General directions of wind generated wave splash (Fig. 1) were determined by use of wind directional frequency data available for the area (Hydrological Atlas of Canada, 1978). As a result, these additional samples were collected along a gradient ranging from fully exposed to fully protected.

Thirteen measurements (Fig. 2) were selected as sufficient to describe overall shell morphology (Pimentel, 1975,

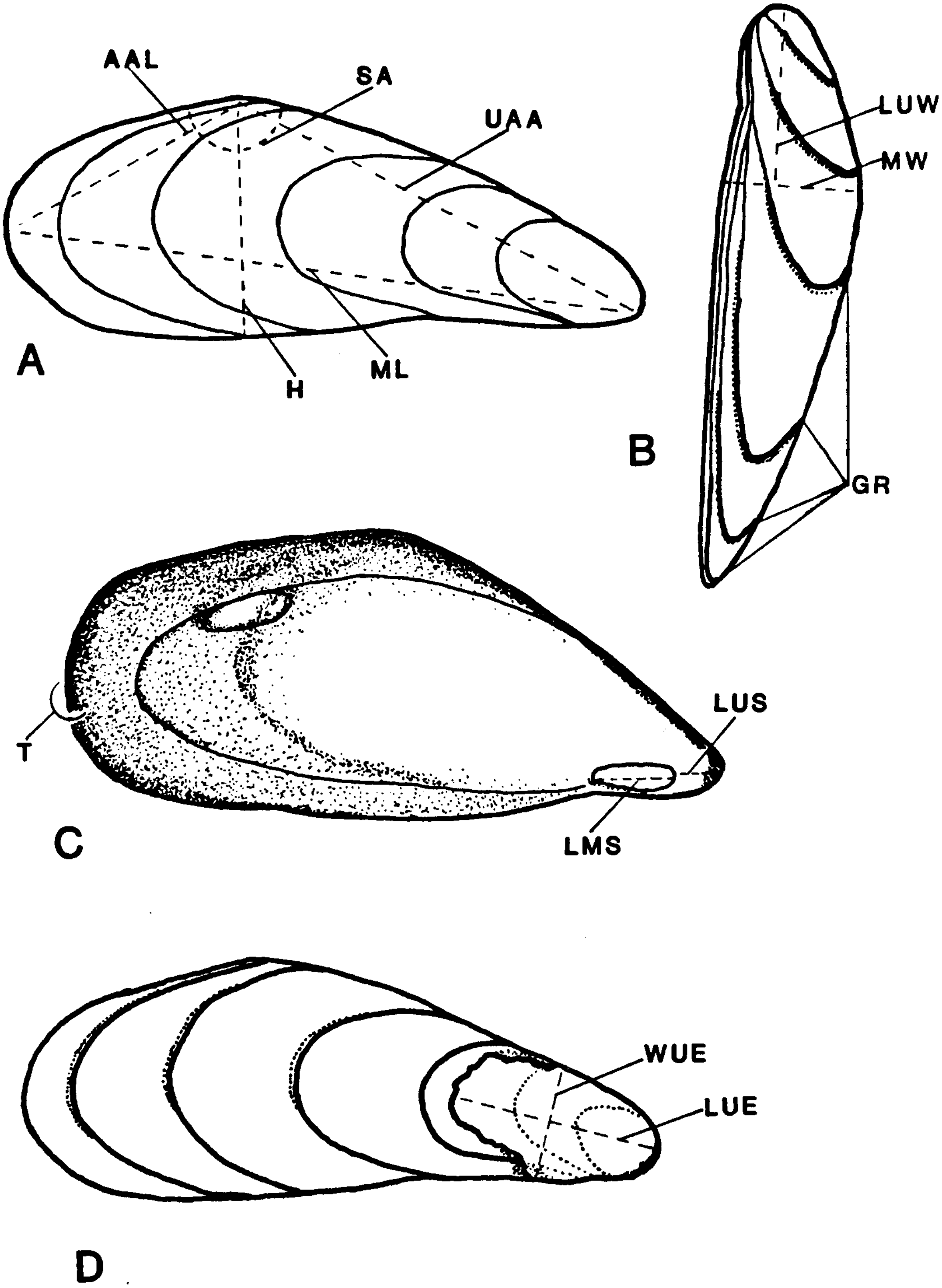
Figure 2. Morphological measurements taken on the shells of *Mytilus californianus* and *Mytilus edulis*

A: ML-maximum length (taken from umbo to posterior margin), H-height (taken on a perpendicular line from midpoint of shell angle to ventral margin), SA-shell angle (from dorsal apex of shell angle to endpoints of maximum length), UAA-umbo to angle apex, AAL-angle apex to maximum length

B: MW-maximum width (measured for 1 valve only), LUW-length (taken on a perpendicular line from umbo to the line of maximum width), GR-growth rings (all visible rings counted)

C: LMS-length of anterior adductor muscle scar, LUS-length from umbo to anterior edge of anterior adductor muscle scar, T-thickness of shell

D: WUE-width of umbonal erosion, LUE-length of umbonal erosion


AAL
SA
UAA
A
H
ML
LUW
MW
B
GR
T
LUS
C
LMS
WUE
LUE
D

Thorpe, 1976). The characteristics measured included characters used in taxonomic keys such as the length of the anterior adductor muscle scar, the length from this scar to the umbo, and the thickness of the shell at the posterior tip (Kozloff, 1974, Light, et. al., 1975), but in addition, characters were measured that, taken as a whole, "covered" the basic form or outline of the mussel shell. All measurements were made to the nearest 0.1 mm using Vernier calipers.

Statistical Analysis of Shell Morphology

The statistical analyses utilized were multivariate analysis of variance, principal components analysis, and discriminant analysis. Pimentel (1975) describes the application of these analyses to problems of morphometrics. Multivariate analysis of variance tests for significant differences between groups, principal components analysis shows which characters account for the greatest degree of variation in the sample, and discriminant analysis was used to select characters for species identification and to assess convergence of shell morphologies.

The samples of *Mytilus californianus* from Seppings Island and *Mytilus edulis* from Bamfield Inlet (the "typical" habitat samples) were compared with multivariate analysis of variance. It was assumed that finding significant differences between these two samples was sufficient to justify using further multivariate methods on these and the other groups.

Each sample in the study was analyzed separately with principal components analysis. Absolute variation was studied using the variance-covariance matrix. The methodology of the procedure was such that the first component generated (a series of correlation coefficients) accounts for the largest proportion of variation in the sample and succeeding components account for progressively smaller amounts of variation. Comparison of samples from different locations shows patterns of variation that are similar or different at these different sites.

The first run of discriminant analysis was done between comparable size classes of _Mytilus californianus_ from Seppings Island and _Mytilus edulis_ from Bamfield Inlet. Direct and stepwise methods were both used. Combinations of characters that were the best discriminators between species were then used to classify mussels from localities of species overlap. In this manner it was possible to determine if characters that accurately classify shells of _Mytilus californianus_ and _Mytilus edulis_ taken from typical habitats retain their accuracy when used to classify shell samples from mixed species sites. Convergence of shell morphologies was measured indirectly by noting the relative percentage of mussels misclassified at species overlap sites. Since the classification technique was based on the separability of the shell morphology, a high percentage of mussels of one species being classified as belonging to a group other than its own implied that those mussels were more similar to the other species in shell morphology.

Results

Distribution of *Mytilus californianus* and *Mytilus edulis*

Mytilus californianus is distributed on intertidal rock from Lennard and Wickanninish Islands to an area just west of the Government wharf in Tofino harbor (Fig. 1), within the harbor and north into Lemmens Inlet its distribution is patchy. Some very large ($>$ 50 mm length) *Mytilus californianus* are found on small boulders projecting out of mudflats. *Mytilus edulis* is common in all parts of Lemmens Inlet and is especially abundant on mudflats to the leeward side of these islands. The two species overlap in several locations, as at Beck, Stone, and Morpheus Islands (Fig. 1).

In Barkley Sound the situation is similar. *Mytilus californianus* predominates on the outer islands and exposed areas and *Mytilus edulis* is most abundant in protected areas such as quiet inlets and leeward sides of islands (Fig. 1). Species overlap is common in the study areas, found on Dixon Island, Ross Islets, Diana Island, Folger Island, and the point just below the Bamfield Marine Station. No overlap was found within the protected reaches of Bamfield and Grappler Inlets.

Analysis of Shell Morphology

Similar size classes of *Mytilus californianus* from Seppings Island and *Mytilus edulis* from Bamfield Inlet were compared using multivariate analysis of variance to test for significant differences between the measured shell parameters. The results (Table 1) show that significant differences do exist (.05 level) between each group.

Principal components analysis of samples of mussels from single species habitats as well as overlap habitats was carried out. Appendix Tables I-VII list the first three components for each group and the corresponding eigenvalues. The first three components account for at least 70% of the total variation, with additional components contributing relatively small amounts.

The first component of each group can be defined as a growth component (Pimentel, 1975) based on all coefficients carrying a positive sign, and reflects the form of the mussel due to an increase in all shell dimensions. Further inspection of the coefficients reveals that their magnitudes are similar at each shell character, possibly reflecting similar patterns in growth in size of *Mytilus californianus* and *Mytilus edulis*.

The second and third components of each group contain both positive and negative coefficients with varying magnitudes at each measurement and are termed shape components (Pimentel, 1975). Shape components contrast

Table I. Multivariate F-table Comparing Similar Size Classes of *Mytilus californianus* from Seppings Island and *Mytilus edulis* from Bamfield Inlet

Size Class	F-Value	Degrees of Freedom
7-16 mm	52.491*	13,80
16-25 mm	62.250*	13,80
25-35 mm	93.274*	13,80
35-50 mm	72.624*	13,80

*significant at the .05 level

patterns of shell variation at different sample sites and give an indication of which characters are most variable at a given sample site. For example, by examining the loadings of the second component on characters WUE (width of umbonal erosion) and LUE (length of umbonal erosion) for _Mytilus_ _californianus_ and _Mytilus_ _edulis_ in all size classes (Appendix Tables I-IV) it is clear that the second component is a shape component reflecting variation in the extent of shell erosion. The remaining samples of _Mytilus_ _californianus_ and _Mytilus_ _edulis_ (Appendix Tables V-VII) do not show a consistent pattern for the second component. The loadings on characters WUE and LUE (extent of shell erosion) are still prominent, but in addition, high loadings are found on characters GR, LMS, and LUS (number of growth rings, adductor muscle scar length, and length from scar to umbo).

Shape components of _Mytilus_ _californianus_ and _Mytilus_ _edulis_ from overlapping habitats are similar. Factor loadings for the third component of character T (shell thickness) at Folger Island indicates similar degrees of variation in both species. The same is true for the second component loadings for characters LMS and LUS (measurements of the posterior adductor muscle) in _Mytilus_ _californianus_ and _Mytilus_ _edulis_ at Folger Island.

Similar size classes of _Mytilus_ _californianus_ and _Mytilus_ _edulis_ from their typical habitats were paired and run through discriminant analysis. A direct procedure was employed and classification, based on all 13 measurements, averaged 97.8% accurate (range 95-99%). The use of 13 measurements to separate species is not readily applicable to field purposes, even though they result in high accuracy. A smaller set of characters was obtained by using stepwise discriminant analysis, entering the characters in various groupings, and observing the classification results. From all the combinations possible, two pairs of characters gave the most consistent results, measurements UAA and AAL (umbo to angle apex and angle apex to maximum length) and LMS and LUS (length of anterior adductor muscle scar and length of anterior edge of muscle scar to the umbo) (Fig. 2). Appendix Tables VII-X show classification results of these character pairs at several sample sites in Barkley Sound. When classification results are averaged at all sample sites for measurements UAA-AAL and LMS-LUS the percent correct classification approaches 90% (Table II). If measurements UAA-AAL and LMS-LUS are combined in discriminant analysis, the percent correct classification is 95%, closely approximating the value obtained using all measurements.

Thorpe (1976) discusses some theoretical and practical problems in assessing rival affinities and multivariate techniques useful in such cases. To identify convergence in this situation, I will use the percent misclassification of either species as a measure of similarity. Appendix

Table II. Comparison of Classification Results at All Sample Sites Using Various Character Combinations

Species	Characters Used	Results(%)
Mytilus californianus	UAA,AAL	88
	LMS,LUS	88
	UAA,AAL,LMS,LUS	95
	All	97.8
Mytilus edulis	UAA,AAL	86.7
	LMS,LUS	87
	UAA,AAL,LMS,LUS	93
	All	98

Tables VIII and IX show classification results for two sites of population overlap, Folger and Dixon Islands, using characters UAA and AAL (umbo to angle apex and angle apex to maximum length) and LMS and LUS (length of anterior adductor muscle scar and length of anterior edge of muscle scar to the umbo). The percentage of correct classification varies from 68% to 92%. Appendix Table X shows classification results for samples from typical habitats, *Mytilus californianus* from Diana Island and *Mytilus edulis* from Grappler Narrows. Classification is 100% accurate using characters UAA and AAL and 86% accurate using LMS and LUS. Higher classification percentages at typical habitat sites versus lower classification percentages at overlap sites indicates shell form convergence at overlap sites in the characters measured.

Discussion

Population Overlap

The results obtained show that overlap occurs commonly between *Mytilus californianus* and *Mytilus edulis*. This is due to the wide habitat range available in Barkley Sound and Clayoquot Sound. In habitats where overlap occurs, there is sufficient wave shock to keep *Mytilus californianus* free of debris yet not strong enough to sweep away the weaker byssal attachment of *Mytilus edulis* (Harger, 1971). The extension of *Mytilus californianus* into quiet water areas is dependent on the presence of wave splash or current of sufficient force to prevent burial in the sediments (Harger, 1971). Likewise, the upper limit of wave shock that can be endured by *Mytilus edulis* is a function of the strength of its byssal fibers and the force required to break their hold on the substrate (Harger, 1971).

Mytilus edulis can apparently survive in a wider range of physical and environmental variables than can *Mytilus californianus* (Bayne, 1977). These variables include salinity, exposure, temperature, and burial by sediments. This could be predicted when the overall geographic distribution of both species is considered; *Mytilus edulis* is a cosmopolitan species while *Mytilus californianus* is restricted to the Pacific coast of North America. Bayne (1977) partly attributes the wide distribution of *Mytilus edulis* to its adaptability to the environment. This adaptability of *Mytilus edulis* is probably the reason it occurs in so many different situations on the west coast of Vancouver Island.

A common method of geographic expansion by marine invertebrates is the dispersal of pelagic larval stages by water currents (Thorson, 1964). Both *Mytilus californianus* and *Mytilus edulis* have pelagic larval stages of approximately two weeks (Bayne, 1977) during which the larvae are at the mercy of water currents to carry them to a settlement site. Some of the mussel larvae, at metamorphosis and settling, will most certainly encounter habitats different from their parents in a region as varied as Barkley and Clayoquot Sounds. If this area is not typical for the species but conditions are such to allow survival to adult size, the mussels will persist.

Harger (1971) recognized the ability of _Mytilus edulis_ to adapt to exposed conditions but concluded that coexistence between _Mytilus californianus_ and _Mytilus edulis_ is probably an uncommon event, based on the number of overlap situations he observed. My results indicate that overlap is fairly common in the study area on Vancouver Island. Physical differences between the sites are notable. The coastline near Santa Barbara (Harger's study area) is relatively uniform compared to the shoreline of Barkley and Clayoquot Sounds. Indentations of the shoreline and offshore islands in Barkley and Clayoquot Sounds results in sudden changes in exposure over short distances. This is especially true in considering small islands along the coast where conditions on the leeward side will be quite different than on the exposed side. My results show that population overlap is especially prevalent on small islands within the sounds. _Mytilus californianus_ is generally prevalent on the exposed portions and _Mytilus edulis_ is common on the protected leeward sides with areas of overlap at points in between these two extremes.

Harger (1971) suggests that true coexistence between

Mytilus californianus and *Mytilus edulis* will never occur in a dynamic environment such as the intertidal zone. *Mytilus californianus* will eventually outcompete *Mytilus edulis* in exposed situations. However, if *Mytilus edulis* larvae settle in an exposed habitat, reach maturity and spawn before being forced out by competition with *Mytilus californianus*, young *Mytilus edulis* will begin the cycle anew. Harger (1971) has shown that *Mytilus edulis* does reach maturity at a smaller size and in less time than does *Mytilus californianus*. Studies in competition between the two species in areas of extensive habitat overlap are needed to unravel the biological interactions that are taking place between *Mytilus californianus* and *Mytilus edulis*. For instance, a recent study by Fankboner, Blaylock and de Burgh (1978) has shown that *Mytilus edulis* is capable of removing significantly greater portions of dissolved and particulate organic carbon from seawater than does *Mytilus californianus*. The advantage is due in part to the fact that *Mytilus edulis* has a more extensive gill surface areas than does a similar sized *Mytilus californianus*, thus in filtering a given amount of seawater *Mytilus edulis* will accumulate greater concentrations of dissolved and particulate carbon compounds in its body than will *Mytilus californianus*. It is probable that other means exist by which one or the other species may more effectively utilize a given resource and thus allow population overlap to exist.

Morphological Shell Variation

The results of principal components analysis have shown that the first component of shell variation is a growth component while the second and third components represent variation in shape. Variation in the second and third components of Mytilus californianus and Mytilus edulis indicate that environmental factors are influencing shell shape. Shape components of Mytilus californianus and Mytilus edulis taken from overlapping habitats are quite similar. This could indicate a similar response by each species to the same stimulus. In the freshwater mussel, Lampsilis radiata, Green (1972) has shown that environmental factors play such a significant role in shell morphology that you can predict the environmental characteristics from examination of any given shell of the species. Similarly, the degree of wave shock encountered by Mytilus californianus or Mytilus edulis can be suggested by examining the degree of shell erosion, the ratio of the two lengths along the dorsal edge (measurements UAA and AAL), and shell thickness. In mussels living in calm waters, increased smoothness of the shell, lack of umbonal erosion, and shell lengthening are obvious. Epifaunal bivalves such as Mytilus spp are normally more variable in shape and thus more reflective of environmental conditions (Kauffman, 1969).

The results of my discriminant analysis demonstrate that external shell characteristics can separate morphological variants of *Mytilus californianus* and *Mytilus edulis* with a 98% success rate. A study by Seed (1968) on the British Coast using only length, width, and depth measurements of shells of *Mytilus* spp showed that these characters are not good indicators of species identity, results I also obtained using solely those three characters. I believe this helps to illustrate the power and usefulness of a multivariate approach to a problem of this type: enough measurements are chosen to describe the form of the shell (13 in this study) and the methodology is such that all measurements are independent of each other. Results are obtained by observing the discriminating power of any number of combinations.

Comparing the relationship of measurements UAA and AAL (umbo to angle apex and angle apex to maximum length) to separate *Mytilus californianus* and *Mytilus edulis* is a valuable field identification tool. The measurements can be done easily and quickly. In *Mytilus californianus* measurement UAA is usually greater than or equal to measurement AAL. In *Mytilus edulis* measurement AAL is greater than or equal to measurement UAA. In situations where measurements UAA and AAL are roughly equal and separation is difficult, I would recommend using the anterior adductor muscle scar measurements as outlined by Light, et. al. (1975) to further identify the mussel. The combination of these two character pairs results in a high percentage of correct classification. I prefer the external measurements for quick field usage simply because they are easier to compare. In questionable areas, where overlap is certain, I would recommend using all four characters for best results.

Phillips, et. al. (1973) have shown that shell form of a species is most uniform within that animal's typical habitat. My classification results for Mytilus californianus and Mytilus edulis support this view. Since both species show strong responses to environmental influences on shell morphology it is not surprising that their morphologies converge somewhat in areas of overlap where both species are subject to equal physical stresses from the environment.

Appendix

Appendix Table I. Principal Components of *Mytilus edulis* from Bamfield Inlet and *Mytilus californianus* from Seppings Island (Size = 7-16 mm)

Mytilus edulis — Eigenvalues/Loadings

Character	Components 1	2	3
ML	.8987	-.2011	-.0141
H	.9277	-.1200	-.0610
SA	.1375	-.3454	-.4479
UAA	.8835	-.2045	-.0574
AAL	.9010	-.0677	-.0329
MW	.9284	-.0871	-.0781
LUW	.8640	-.0954	-.1547
GR	.6651	-.0433	-.2975
LMS	.6282	.0164	.6307
LUS	.7440	.0698	.4543
T	.1292	.1803	.4596
WUE	.4170	.8044	-.2254
LUE	.4371	.8098	-.1938
Eigenvalue	6.6537	1.5800	1.2312

Mytilus californianus — Eigenvalues/Loadings

Character	Components 1	2	3
ML	.9715	-.1270	.0077
H	.9154	-.0207	-.0833
SA	.0184	-.5578	.5526
UAA	.9280	-.0896	-.0668
AAL	.9232	-.0731	.0917
MW	.9453	-.0541	-.0141
LUW	.9110	-.0866	-.0851
GR	.6325	-.1301	-.1439
LMS	.8749	-.1630	.0513
LUS	.8602	-.1588	.0881
T	.3415	.2077	-.6327
WUE	.4891	.7106	.3488
LUE	.5343	.7041	.2667
Eigenvalue	7.7659	1.4653	.9569

Appendix Table II. Principal Components of *Mytilus edulis* from Bamfield Inlet and *Mytilus californianus* from Seppings Island (Size = 16-25 mm)

Mytilus edulis — Eigenvalues/Loadings

Character	Components 1	2	3
ML	.8987	-.1073	-.2542
H	.5941	-.1771	-.2617
SA	.0027	-.0019	-.5305
UAA	.8124	-.1053	-.2210
AAL	.8421	-.0120	-.2313
MW	.8312	.0724	-.0730
LUW	.8066	.0079	-.0852
GR	.3842	-.3705	.0050
LMS	.5647	-.3719	.6193
LUS	.6535	-.3223	.5591
T	.1974	.4512	.1834
WUE	.4319	.7905	.1665
LUE	.4646	.7971	.1379
Eigenvalue	5.2061	1.8715	1.3060

Mytilus californianus — Eigenvalues/Loadings

Character	Components 1	2	3
ML	.9154	-.0124	.0644
H	.8930	-.0341	-.1677
SA	.0625	.2626	.7420
UAA	.9365	-.0370	-.1204
AAL	.7536	.0493	.2403
MW	.9156	.0228	-.1504
LUW	.8411	.1227	.0771
GR	.4853	-.4667	.0267
LMS	.7943	-.2677	.1861
LUS	.7499	-.3206	.2529
T	.3125	-.1115	-.6453
WUE	.3524	.7243	-.1314
LUE	.4219	.7402	-.0625
Eigenvalue	6.4458	1.5716	1.2044

Appendix Table III. Principal Components of *Mytilus edulis* from Bamfield Inlet and *Mytilus californianus* from Seppings Island (Size = 25-35 mm)

Mytilus edulis Eigenvalues/Loadings

Character	Components 1	2	3
ML	.9478	.0334	-.1524
H	.8598	-.0933	-.3006
SA	.0080	.1981	.2409
UAA	.8471	-.0213	-.2801
AAL	.8970	.0151	-.1343
MW	.8713	.1204	-.2316
LUW	.8844	.0400	-.1624
GR	.4274	-.4602	.0646
LMS	.6488	-.4445	.4280
LUS	.6916	-.4192	.3877
T	.1326	-.3154	.4498
WUE	.6524	.5973	.3813
LUE	.5670	.6249	.4103
Eigenvalue	6.5129	1.4976	1.2018

Mytilus californianus Eigenvalues/Loadings

Character	Components 1	2	3
ML	.9389	-.0491	-.1325
H	.7357	-.1308	-.3217
SA	.4196	.2653	.3663
UAA	.8790	-.0272	-.2042
AAL	.8148	-.0732	-.0734
MW	.8986	.0500	-.1015
LUW	.6570	.2917	.0004
GR	.3550	-.3965	-.4661
LMS	.6021	-.4845	.5364
LUS	.6711	-.4236	.5199
T	.3147	-.0182	-.1193
WUE	.4029	.7438	.0294
LUE	.3782	.7953	.1504
Eigenvalue	5.6179	1.9410	1.1255

Appendix Table IV. Principal Components of *Mytilus edulis* from Bamfield Inlet and *Mytilus californianus* from Seppings Island (Size = 35-50 mm)

Mytilus edulis

Character	Eigenvalues/Loadings Components 1	2	3
ML	.9586	-.0693	-.1728
H	.7513	-.2910	-.3854
SA	.5249	.4061	.2664
UAA	.8440	-.1601	-.3019
AAL	.9089	-.1275	-.1645
MW	.9158	.0031	-.1447
LUW	.8189	.0053	-.2040
GR	-.1654	-.1080	-.5518
LMS	.4692	-.5867	.6016
LUS	.5174	-.5998	.5345
T	.3764	.4434	.0586
WUE	.6415	.5691	.2445
LUE	.6708	.5242	.2838
Eigenvalue	6.3247	1.8071	1.5260

Mytilus californianus

Character	Eigenvalues/Loadings Components 1	2	3
ML	.9425	.0057	-.1518
H	.7678	-.4350	-.0489
SA	.1143	.5436	.1628
UAA	.7720	-.2292	-.0083
AAL	.7551	.1064	-.2706
MW	.8703	.1183	-.1895
LUW	.7336	.1592	-.2806
GR	.0651	-.6468	-.4293
LMS	.4300	-.5424	.6289
LUS	.3840	-.5835	.6567
T	.1293	-.0082	-.1382
WUE	.4631	.6791	.3445
LUE	.4236	.7772	.2531
Eigenvalue	4.6998	2.7063	1.4528

Appendix Table V. Principal Components of *Mytilus edulis* from Grappler Narrows and *Mytilus californianus* from Diana Island.

Mytilus edulis — Eigenvalues/Loadings

Character	Components 1	2	3
ML	.9629	.0698	-.0998
H	.8503	.3126	-.3301
SA	.4489	-.4853	.4182
UAA	.9244	.1131	-.1472
AAL	.9112	.1113	-.0934
MW	.9429	-.0068	-.1409
LUW	.9090	-.0490	.0209
GR	-.1113	.6050	-.5738
LMS	.3965	.6631	.4937
LUS	.4689	.6226	.5659
T	.2018	-.1426	.3275
WUE	.6434	-.5576	-.1159
LUE	.6679	-.5444	.0187
Eigenvalue	6.5344	2.1868	1.3588

Mytilus californianus — Eigenvalues/Loadings

Character	Components 1	2	3
ML	.9590	.1819	.0727
H	.9234	.2000	-.0789
SA	-.0923	.2898	.8591
UAA	.9551	.1366	.0520
AAL	.9148	.2198	.0994
MW	.9379	.0691	.0363
LUW	.8274	-.0082	.0680
GR	-.0326	.8180	-.3673
LMS	.8008	.0317	-.1079
LUS	.8110	.0403	-.1289
T	.1746	-.4980	-.2347
WUE	.6883	-.4501	-.1240
LUE	.6301	-.5660	.2490
Eigenvalue	7.2954	1.6715	1.0637

Appendix Table VI. Principal Components of _Mytilus edulis_ and _Mytilus californianus_ from Folger Island

Mytilus edulis — Eigenvalues/Loadings

Character	Components 1	2	3
ML	.9561	-.0222	.0365
H	.9349	-.1307	-.0856
SA	-.2112	-.1485	.6145
UAA	.8279	-.3437	-.0036
AAL	.8285	-.0134	.0502
MW	.7806	-.0379	-.1669
LUW	.8912	-.1880	.1574
GR	.3062	.6454	-.3143
LMS	.4782	.5978	.5241
LUS	.5790	.6298	.4179
T	.3141	-.5901	.5038
WUE	.8149	-.0872	-.3418
LUE	.8875	.0149	-.1686
Eigenvalue	6.8161	1.7213	1.3886

Mytilus californianus — Eigenvalues/Loadings

Character	Components 1	2	3
ML	.9591	.0744	-.0624
H	.8736	.2327	-.0088
SA	.4293	-.5412	-.4178
UAA	.8774	.2082	.1801
AAL	.7140	-.0294	-.3648
MW	.9373	-.1085	.0982
LUW	.8921	-.0256	.1658
GR	.0043	.6720	-.2666
LMS	.8282	.4378	.0378
LUS	.8282	.4378	.0378
T	.3774	-.3037	.8139
WUE	.8256	-.4380	-.1384
LUE	.7750	-.4274	-.1870
Eigenvalue	7.6180	1.7109	1.1717

Appendix Table VII. Principal Components of *Mytilus edulis* and *Mytilus californianus* from Dixon Island

Mytilus edulis — Eigenvalues/Loadings

Character	Components 1	2	3
ML	.8230	.1384	.1447
H	.2143	.9178	.0115
SA	.5866	-.5121	.1748
UAA	.8202	.1156	-.2045
AAL	.4493	.7101	-.1316
MW	.8264	.2701	-.3635
LUW	.7513	.2036	-.4075
GR	-.1050	.7140	-.0931
LMS	.4153	.2110	.8199
LUS	.5684	.2811	.6610
T	.4508	-.5332	.0237
WUE	.7587	-.4313	-.1242
LUE	.7676	-.5291	-.0450
Eigenvalue	5.0790	3.1394	1.5448

Mytilus californianus — Eigenvalues/Loadings

Character	Components 1	2	3
ML	.9594	-.0824	.0180
H	.9094	-.2546	.0108
SA	.2484	.7116	-.2695
UAA	.9429	-.2504	.0243
AAL	.9342	-.0790	.0307
MW	.9393	.1674	.0427
LUW	.8021	.3715	-.0107
GR	.3159	.3042	.5986
LMS	.7197	-.5918	.0573
LUS	.7442	-.4864	-.0043
T	-.1156	.2137	.8114
WUE	.7482	.4465	-.0726
LUE	.7086	.5234	-.1687
Eigenvalue	7.3435	2.0113	1.1309

Appendix Table VIII. Comparison of Classification Results Between *Mytilus edulis* and *Mytilus californianus* from Folger Island

Character Pair: UAA-AAL (umbo to angle apex and angle apex to maximum length)

Actual Group	No. of Cases	Predicted Membership Group 1	Predicted Membership Group 2
Group 1 *Mytilus edulis*	25	23 92%	2 8%
Group 2 *Mytilus californianus*		3 12%	22 88%

Percent of Grouped Cases Correctly Classified: 90%

Character Pair: LMS-LUS (length, anterior adductor muscle scar and length, umbo to anterior edge of anterior adductor muscle scar)

Actual Group	No. of Cases	Predicted Membership Group 1	Predicted Membership Group 2
Group 1 *Mytilus edulis*	25	20 80%	5 20%
Group 2 *Mytilus californianus*	25	2 8%	23 92%

Percent of Grouped Cases Correctly Classified: 86%

Appendix Table IX. Comparison of Classification Results Between *Mytilus edulis* and *Mytilus californianus* from Overlapping Habitats on Dixon Island

Character Pair: UAA-AAL (umbo to angle apex and angle apex to maximum length)

Actual Group	No. of Cases	Predicted Membership Group 1	Predicted Membership Group 2
Group 1 *Mytilus edulis*	25	17 68%	8 32%
Group 2 *Mytilus californianus*	25	6 24%	19 76%

Percent of Grouped Cases Correctly Classified: 72%

Character Pair: LMS-LUS (length, anterior adductor muscle scar and length, umbo to anterior edge of anterior adductor muscle scar)

Actual Group	No. of Cases	Predicted Membership Group 1	Predicted Membership Group 2
Group 1 *Mytilus edulis*	25	20 80%	5 20%
Group 2 *Mytilus californianus*	25	2 8%	23 92%

Percent of Grouped Cases Correctly Classified: 86%

Appendix Table X. Comparison of Classification Results Between *Mytilus edulis* from Grappler Narrows and *Mytilus californianus* from Diana Island

Character Pair: UAA-AAL (umbo to angle apex, and angle apex to maximum length)

Actual Group	No. of Cases	Predicted Membership Group 1	Predicted Membership Group 2
Group 1 *Mytilus edulis*	25	25 100%	0 0%
Group 2 *Mytilus californianus*	25	0 0%	25 100%

Percent of Grouped Cases Correctly Classified: 100%

Character Pair: LMS-LUS (length, anterior adductor muscle scar and length, umbo to anterior edge of anterior adductor muscle scar)

Actual Group	No. of Cases	Predicted Membership Group 1	Predicted Membership Group 2
Group 1 *Mytilus edulis*	25	20 80%	5 20%
Group 2 *Mytilus californianus*	25	2 8%	23 92%

Percent of Grouped Cases Correctly Classified: 86%

List of References

Abbott, R.T. and R. Jensen. 1967. Molluscan faunal changes around Bermuda. Science. 155: 687-688.

Anonymous. 1962. Information Bulletin No. 13, Feb., 1962. Nautical charts etc. covering the southern British Columbia Coast including Vancouver Island. Canadian Hydrographic Service, Dept. of Mines and Technical Surveys. Ottawa.

Bayne, B.L. 1977. Marine Mussels, their ecology and physiology. Cambridge University Press. London. 506pp.

Crothers, J. 1974. On variation in Nucella lapillus (L.): shell shape in populations from the Bristol Channel. Proc. Malac. Soc. Lond. 41(2): 157-170.

Fairbridge , W.S. 1953. A population study of the Tasmanian "commercial" scallop, Notovala meridionalis (Lamellibranchiata:Pectinidae). Aust. J. Mar. Fresh. Res. 4: 1-41.

Fankboner, P.V., W.M. Blaylock, and M.E. deBurgh. 1978. Accumulation of ^{14}C-labelled Algal Exudate by Mytilus californianus and Mytilus edulis. Veliger. 21(2): 276-282.

Fox, D.L., and W.R. Coe. 1943. Biology of the California sea mussel Mytilus californianus. II. Nutrition, metabolism, growth and calcium deposition. J. exp. Zool. 93: 205-249.

Green, R.H. 1972. Distribution and Morphological Variation of Lampsilis radiata (Pelecypoda:Unionidae) in some central Canadian lakes: a multivariate statistical approach. J. Fish. Res. Board Canada. 29(11): 1565-1570.

Harger, J.R.E. 1970a. The effect of wave impact on some aspects of the biology of sea mussels. Veliger. 12(4): 401-414.

Harger, J.R.E. 1970b. Comparisons among growth characteristics of two species of sea mussels, Mytilus edulis and Mytilus californianus. Veliger. 13(1): 44-56.

Harger, J.R.E. 1971. Competitive Co-Existence: Maintenance of Interacting Associations of the Sea Mussels Mytilus edulis and Mytilus californianus. Veliger. 14(4): 387-410

Hydrological Atlas of Canada. 1978. Surveys and Mapping Branch, Department of Energy, Mines, and Resources. Ottawa. 70pp.

Kauffman, E.G. 1969. Form, function, and evolution. N219-N205. IN Moore, R.C. (Ed.). Treatise on invertebrate paleontology. Part N. Mollusca. 6. Bivalvia 1. Univ. Kansas. Geol. Soc. America. 952pp.

Kitching, J.A., L. Muntz, and F.J. Ebling. 1966. The Ecology of Lough Ine. XV. The ecological significance of shell and body forms in Nucella. J. Anim. Ecol. 35: 119-126.

Kozloff, E. 1974. Key to the marine invertebrates of Puget Sound, the San Juan Archipelago, and adjacent waters. University of Washington Press. Seattle. 226pp.

Phillips, B.F., N.A. Campbell, and B.R. Wilson. 1973. A multivariate study of geographic variation in the whelk Dicathais. J. Exp. Mar. Bio. Ecol. 11(1): 27-69.

Pickard, G.L. 1963. Oceanographic Characteristics of Inlets of Vancouver Island, British Columbia. J. Fish. Res. Board Canada. 20(5): 1109-1144.

Pimentel, R.A. 1975. Morphometrics: the multivariate analysis of biological data. California Polytechnic State University. San Luis Obispo. 150pp.

Purchon, R.D. 1939. The effect of the environment upon the shell of Cardium edule. Proc. Malacog. Soc. London. 23: 256-267.

Quayle, D.B. 1960. The Intertidal Bivalves of British Columbia. British Columbia Provincial Museum. Handbook No. 17. 104pp.

Ricketts, E.F., J. Calvin, and J.W. Hedgpeth. 1968. Between Pacific Tides. Fourth Ed. Stanford University Press. Stanford. 614pp.

Russell, P.J.C. 1972. A significance in the number of ribs on the shells of two closely related Cardium species. J. Conch. London. 27(5-6): 401-409.

Seed, R. 1968. Factors Influencing Shell Shape In The Mussel *Mytilus edulis*. J. mar. biol. Assoc. U.K. 48: 561-584.

Smith, R.I., and J.T. Carlton (Eds.). 1975. Light's Manual: Intertidal Invertebrates of the Central California Coast. Third Edition. Univ. California Press. Berkeley. 716pp.

Thorpe, R.S. 1976. Biometric Analysis of Geographic Variation and Racial Affinities. Biol. Rev. 51: 407-452.

Thorson, G. 1964. Light as an ecological factor in the dispersal and settlement of larvae of marine invertebrates. Ophelia 1: 167-208.