THE MORPHO-ECOLOGICAL CHARACTER OF COASTAL SAND DUNES ON THE NORTHERN TOMBOLO, LES ILES-DE-LA-MADELEINE, QUEBEC

BY

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A Research Paper

Submitted to the Department of Geography

in Fulfillment of the Requirements

of Geography 4C6

McMaster University

April 1990

ABSTRACT

There are marked differences in the morphology and vegetation of the west (Dune du Nord) and east (Dune du Sud) coast dunes of Les Iles-de-la-Madeleine in the southern Gulf of St. Lawrence. The west coast dunes consist mainly of blown-out foredunes succeeded inland by large parabolic dunes. Vegetation is dominated by *Ammophila breviligulata* with < 40% cover, except for the rich flora of cranberry bog communities that occur in deflation hollows at the base of the parabolic scarps. One section of Dune du Nord has more stable, heath-covered dunes that have been extensively modified by deflation, creating a complex topography. On the east coast, the stable dunes support species rich heath and grassland vegetation with higher cover (60-100%). The southern part is a wide complex of progradational ridges, now being overridden on the seaward side by a narrow blown-out strip dominated by *A. brevliligulata*. To the north, the topography is simple, with *A. brevliligulata* on the foredune that is quickly succeeded by grassland vegetation on a narrow dune flat. This contrast in morpho-ecological conditions between the two coasts is related to the differences in wave energy described by Owens (1977), wind regime, and existing topography. The present research paper provides a Canadian example of Hesp's (1988) model of the surfzone and wave energy interaction with dune morphology and ecology.

ACKNOWLEDGEMENTS

My sincere gratitude is extended to the following people who contributed to this research effort: Dr. S. Brian McCann, who gave me the chance to investigate the dunes on Les Iles-de-la-Madeleine. His advice and assistance in the field were invaluable, as was his supervision during the year. Dr. Glen MacDonald helped with the vegetation data analysis by running the cluster program, and he reviewed a draft of the paper. Louise McCann assisted in surveying two of the transects on a hot day. Mary-Lou Byrne and Joyce Lundberg contributed to the identification of the plants, Bob Bignell developed the photographs, and Dr. S.M. Taylor gave helpful comments in his role as course supervisor. The research was supported by a Natural Sciences and Engineering Research Council of Canada Undergraduate Research award.

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INTRODUCTION

1.1 INTRODUCTION

Coastal sand dune development will occur if two conditions are met: 1) there is an adequate supply of well-sorted beach sand, and 2) there are winds capable of transporting this sand away from the beach. Although the presence of vegetation is not a basic requirement (Cooper 1958), it does have an important influence on coastal sand dune formation.

This paper is a study of dune character, or dune morphology and vegetation. With coastal sand dunes, morphology can be characterized in terms of the size, shape and orientation of the dunes. "Vegetation" is a broad term that will be described in this paper by three parameters: number of species and relative species cover at a location, and community zonation on the dunes.

It has long been recognized that one of the basic controls of dune morphology is the wind regime. Recent developments in the research have also acknowledged the importance of wave energy and surfzone-beach interaction on the morphology and vegetation of coastal sand dunes (Hesp 1988).

1.2 PURPOSE

The purpose of this research paper is to determine the effects of differences in wave energy and wind regime on the character of adjacent coastal sand dune systems on the northern tombolo of Les Iles-de-la-Madeleine, Quebec. A comparative model of the morpho-ecological condition of the dunes on the higher energy, west-facing coast and the lower energy, east-facing coast will be proposed.

1.3 LITERATURE REVIEW

Two authors (Pye 1983, Pethick 1984) have written good overviews on the topic of vegetated coastal sand dunes, covering the various components of the morpho-ecological system. This short review will discuss aeolian sand transport, a classification of coastal dunes, wave energy in relation to dune morphology, and dune vegetation.

1.3.1 AEOLIAN SAND TRANSPORT

The formation of coastal sand dunes requires sand to be transported inland by wind. Most descriptions of this process are based on a classic work by Bagnold (1941). Wind experiences a frictional drag at the surface, producing a logarithmic wind profile and a wind velocity of zero at some height Z_0, the surface roughness height. For a bare sand surface Z_0 is approximately 1/30 of the average grain size. The mean velocity at height Z is :

$$V = 5.75\ V^{*} \log(Z/Z_0) \qquad \text{(Ranwell 1972)}$$

where V^{*} is drag velocity

Vegetation increases the roughness of the surface and causes Z_0 to rise, producing lower wind velocities near the surface. Experiments have shown that Z_0 increases to about 1mm with Ammophila breviligulata, a common dune building plant (Pye 1983). This is 30 times the bare surface value of 0.03mm with 1mm average grain size (Pethick 1984).

Raising the roughness height decreases the wind shear velocity at the surface. Gares (1988) shows that the amount of sand transported by wind is most closely related to the cube of the wind shear velocity. This means there is decreased removal and increased deposition of sand in the presence of plants (Hesp 1983).

The dominant process of aeolian sand transport is saltation. In saltation, a grain of sand is entrained into the air by the wind. Upon falling back to the surface, the bombardment initiates the movement of more grains. Smaller contributions to sand transport come from surface creep and suspension.

1.3.2 CLASSIFICATION OF COASTAL SAND DUNES

Over several decades of coastal research several dune classification schemes have been put forward. For this paper, Pethick's (1984) classification will be used; it is similar to Ranwell's (1972).

Mini-dunes and embryo dunes form on the backshore. Mini-dunes occur when tidal litter causes sand deposition. However, once this mini-dune reaches the height of the object, deposition ceases and the dune stops growing (Pethick 1984). Thus, the ultimate height of a mini-dune depends on the size of the obstruction. Embryo dunes are unconnected mounds of sand 1-2m high (Pethick 1984). This height is achieved by the vegetation interaction dune-building process.

As new embryo dunes form to seaward, the unconnected mounds coalesce into a ridge. The continuous ridge closest to the water body is called the foredune, and it is subject to wave erosion on its foreslope. Continued accretion builds up the foredune, with volume and height determined by the sand transport rate and dune migration rate. Transgressive dunes migrate landward by the removal of sand from the foreslope to be deposited on the backslope (Armon and McCann 1979). This can occur in ridges that maintain a straight form over time, or in a system that becomes increasingly complex topographically with blowouts.

Where the winds are strong enough and there is a high rate of sand supply, parabolic dunes form. A spatial example of parabolic dune formation is shown in Fig. 1.1. A temporal succession is also possible if the parabolic form develops from blowouts in the first or second dune ridge before proceeding inland. Parabolic dunes are anchored by vegetation on their downwind arms and are aligned with the prevailing wind direction.

On low energy coasts where foredune erosion is limited, a progradational system may form. Instead of migrating inland, successive low ridges are formed in a seaward direction. Because these dunes are stable, the vegetation growing there is different from active dunes.

1.3.3 WAVE ENERGY IN THE SURFZONE

Although coastal dunes are a backshore landform, there has recently been a recognition of the interaction between surfzone (or nearshore) wave energy and foredune morphology. Wave energy is the amount of energy per length of shoreline transferred from the waves to the shore in the surfzone. In a summary paper, Hesp (1988) presents a morpho-ecological model derived from research on Australian coasts. It holds that sand supply is greater and that there is more salt spray

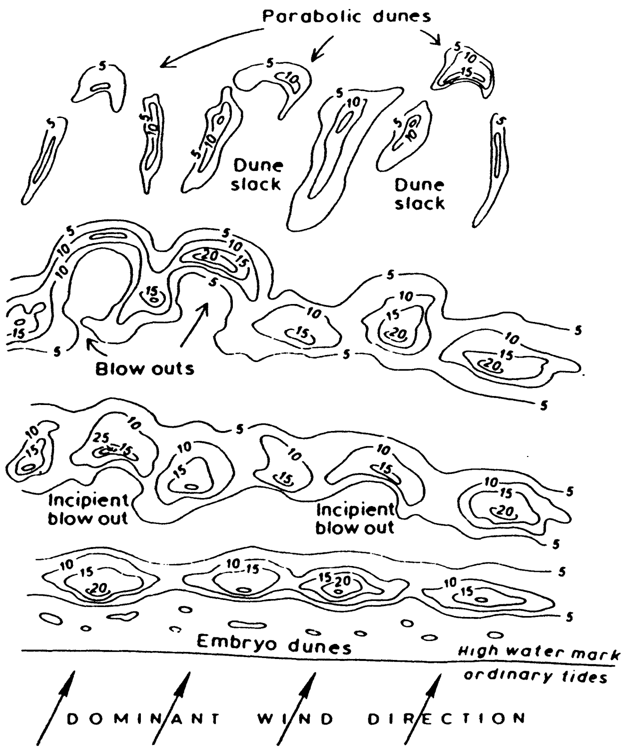


Fig. 1.1 Map showing the spatial development of parabolic dunes. [from Pethick (1984), Fig. 7.11]

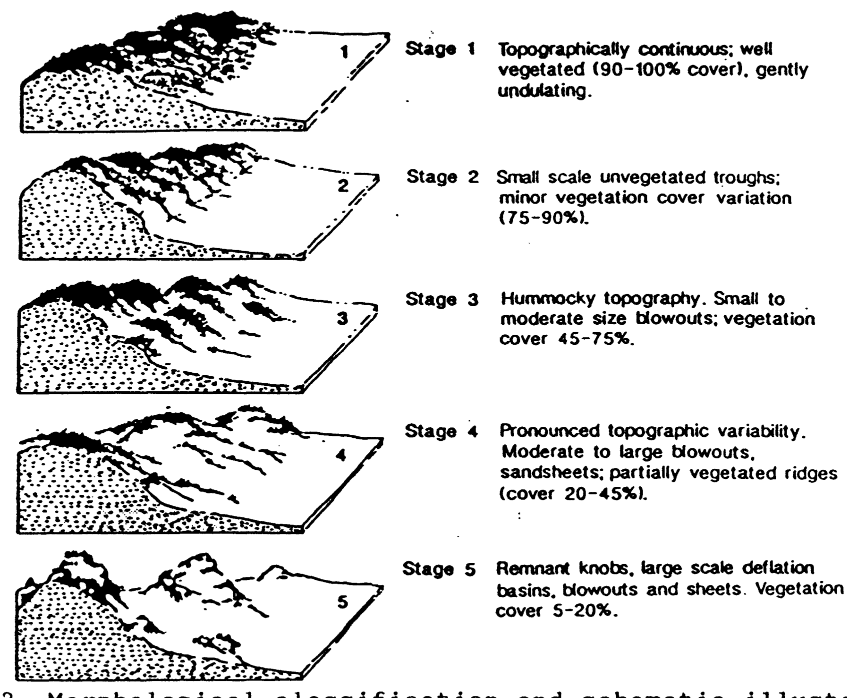


Fig. 1.2 Morphological classification and schematic illustration of southeast Australian foredunes. Surfzone energy increases from Stage 1 to Stage 5. [from Hesp (1988), Fig. 1]

created on higher energy coasts. Thus, on coasts with higher wave energy, the foredunes are larger and more blown out (Fig. 1.2). Vegetation is limited to the more sand burial tolerant and more salt tolerant species- the dune building plants.

1.3.4 COASTAL SAND DUNE VEGETATION

An excellent review of coastal dune vegetation in Europe was written by Ranwell (1972). Although there are differences in the actual species between Europe and North America, the discussion of plant-dune interaction and vegetation succession is applicable to this continent. In North America, the most important species for dune development is Ammophila breviligulata (American beach grass or marram grass). When these plants trap sand the response to the burial is upward growth. This process is described by Ranwell (1958) and Olson (1958). A cycle of plant growth keeping pace with accretion begins and an embryo dune forms. Typical accretion rates are 0.3-1m per year (Ranwell 1972). Studies have shown that continued sand burial is necessary to maintain the vigour of Ammophila breviligulata (Eldred and Maun 1982). Thus, less healthy Ammophila breviligulata plants are found in areas of less sand transport. This species is also capable of surviving the high salt spray concentrations found near the shore. Young (1987, in McLachlan 1988) shows that as one gets further inland from the shore, the amount of sand transported and the amount of salt spray tend to decrease. Therefore the conditions become more favourable for a wider range of plants and a vegetation succession occurs. Generally, pioneer species are replaced by a more diverse flora inland.

Another factor that determines the vegetation at a particular location on a dune system is the availability of groundwater. The low areas between dune ridges are called slacks or swales and are closer to the water table. Swale vegetation is described in detail in a series of articles by Ranwell (1958, 1959, 1960). Swales are usually species-rich compared to the adjacent dune ridges. Often bog communities are found in these locations because the availability of groundwater is high.

1.4 LES ILES-DE-LA-MADELEINE: PHYSICAL SETTING

Les Iles-de-la-Madeleine are located in the southern Gulf of St. Lawrence, a semi-enclosed sea with a microtidal environment (Fig. 1.3). Ocean swell rarely affects the southern Gulf of St. Lawrence (McCann 1979), and waves affecting the coasts of the islands are locally generated. The mean monthly wind direction, recorded at Grindstone, is northwest for all months except July and August when it is southwest (see Appendix 1 for wind record). Prevailing wind direction shall be referred to as generally from the west in this paper.

The predominance of westerly winds and the longer fetches to the west mean that there are very marked differences in the wave climate of the west- and east-facing shores. In the summer (August), Owens (1977) measured the western shore wave energy to be 2.25 times greater than on the east shore; in winter it was 2.95 times greater.

Les Iles-de-la-Madeleine are nine bedrock islands, six of which are connected by double sand tombolos containing enclosed lagoons (Fig. 1.4). Together with the terminal spits the continuous land area extends for 70km in a southwest to northeast direction. Owens and McCann (1980)

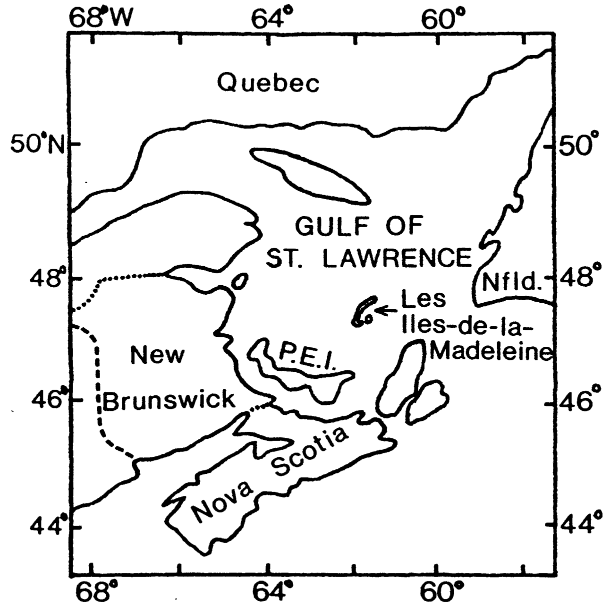


Fig. 1.3 Location of Les Iles-de-la-Madeleine in the southern Gulf of St. Lawrence.

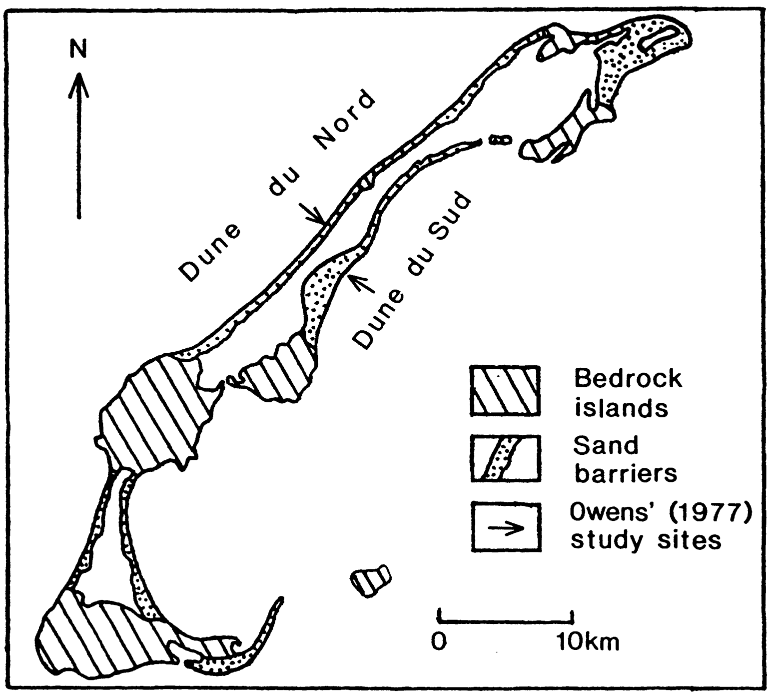


Fig. 1.4 Les Iles-de-la-Madeleine. Dune du Nord and Dune du Sud comprise the double northern tombolo.

describe each of the geomorphic units in some detail. The unit used in this research is the northern tombolo system, comprised of Dune du Nord (west coast) and Dune du Sud (east coast). Dune du Nord is composed of very well sorted medium grained sands. On Dune du Sud there are very well sorted medium- to fine-grained sands, and it has two distinct sections. The northern part is low, narrow and characterized by many recent washover features. To the south is a large complex of progradational ridges. The primary source of the sediment that ultimately supplies the dune building process is believed to be glacial deposits on the Magdalen Shelf.

1.5 STUDY SITES AND PROCEDURE

Five study sites were selected on the basis of air photograph analysis and field reconnaissance to be representative of the morphological and ecological conditions of the two coasts of the northern tombolo (Fig. 1.4). Two of these sites, T1 and T4 (one on each coast), coincide with Owens' (1977) sites of wave energy measurement. Detailed morphological profiles and quantitative vegetation surveys were obtained at each site to allow a numerical comparison to be made of the dune character of the west and east coasts.

1.6 METHODOLOGY

1.6.1 AIR PHOTOGRAPH ANALYSIS

Air photo interpretation was used to develop the classification of dunes and to draw the schematic maps of the study sites discussed in the next chapter. The air photographs used were taken 20 years ago in

1969 and 1970 (see Appendix 6 for details). Use of the photographs in the field showed that the dunes had changed relatively little over the 20 years at the scale required by this study, as most features were easily recognizable. This made it possible to use the photos as a map and for interpreting the morphology and vegetation.

1.6.2 MORPHOLOGICAL PROFILES

At each site, a morphological profile was obtained by using a Wild level and a stadia rod. For three of the sites the profile was aligned perpendicular to the shoreline. At the remaining two (T1 and T2), the line was oblique to the shore, oriented along the direction of migration of large parabolic dunes. These five lines were marked with stakes to ensure proper identification for the vegetation surveys.

1.6.3 VEGETATION TRANSECTS

After the morphological profiles were completed, vegetation transects were made along the same lines following the methods outlined in Smith (1980, App. B). This information was linked to the survey results so the distance from shore was known.

Vegetation zones were identified based on observed changes in total cover and/or type of plants observed. Within each zone, three random placements of a 1m square quadrat were used to record the vegetation information. At each placement of the quadrat, all species present within the boundaries were recorded, along with an estimate of their relative cover (see Fig. A2.1). All plants that did not fall within the quadrats were noted separately to complete the characterization of that zone.

1.6.4 DATA ANALYSIS

Analysis of the data was accomplished in two stages. First, a classification of the dunes on the northern tombolo was developed and schematic maps that illustrate the morpho-ecological character of each study site were prepared. A discussion of dune types and vegetation communities, indicating the differences between the west and east coasts, constitutes Chapter 2 of this paper. The second stage consisted of a detailed analysis of the morphological and ecological conditions along each transect, summarized in a series of composite diagrams presented in Chapter 3.

CHAPTER 2

MORPHO-ECOLOGICAL CHARACTER OF THE DUNES ON THE NORTHERN TOMBOLO

2.1 MORPHO-ECOLOGICAL ANALYSIS

By combining the techniques of air photograph analysis and field observation, it is possible to classify the dunes of the northern tombolo of Les Iles-de-la-Madeleine into four morpho-ecological types (Fig. 2.1). This chapter provides a brief description of each type. Schematic maps for each of the five transect locations shown on Fig. 2.1 have been drawn to complement the discussion, and the photographs in Appendix 2 should also be consulted. Following this, each of the major dune vegetation communities will be described.

2.2 CLASSIFICATION OF DUNE TYPES

2.2.1 TYPE 1: BLOWN-OUT FOREDUNES AND PARABOLIC DUNES

The west coast (Dune du Nord) is dominated by extensive sections of blown-out dunes. Transects 1 and 2 (Figs. 2.2 and 2.3) show these conditions. Dune transgression is occurring with the formation of large parabolic dunes inland of the current foredune. Both transects show two successive parabolic dunes oriented with the trailing arms to the west into the prevailing wind. In each case the parabolic dunes are still actively moving inland. Elsewhere along the west coast parabolic dunes are at various stages of formation.

Blown-out and parabolic dunes are indicative of a dynamic sand transport system and *Ammophila breviligulata* is the dominant vegetation. The wind-scoured scarp faces of the parabolic dunes are partly

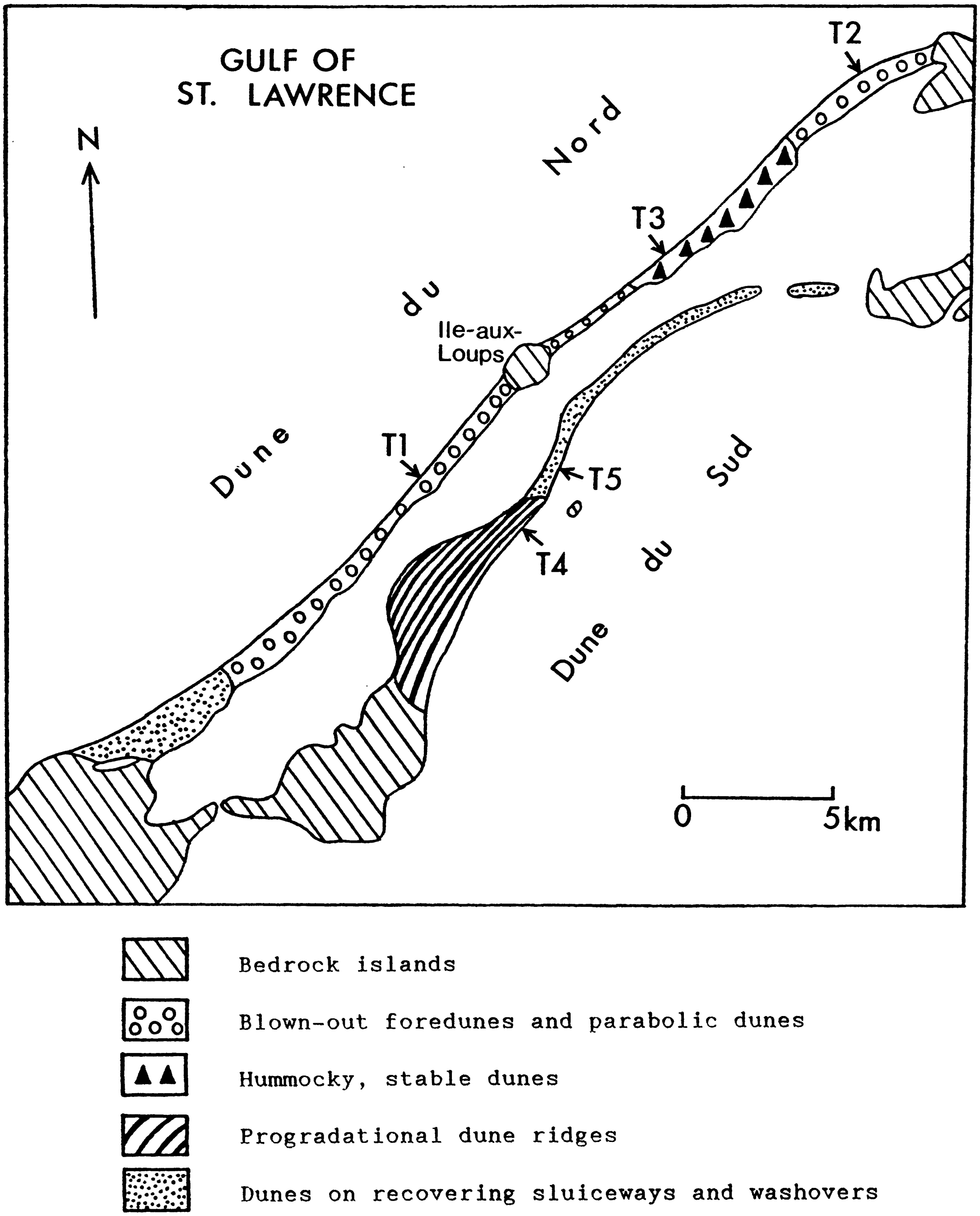


Fig. 2.1 Classification of dune types on the northern tombolo.

Key for Figs. 2.2–2.6:

--- Survey line

Ammophila

Cranberry bog

Grassland

Heath

Marsh

Dune scarp

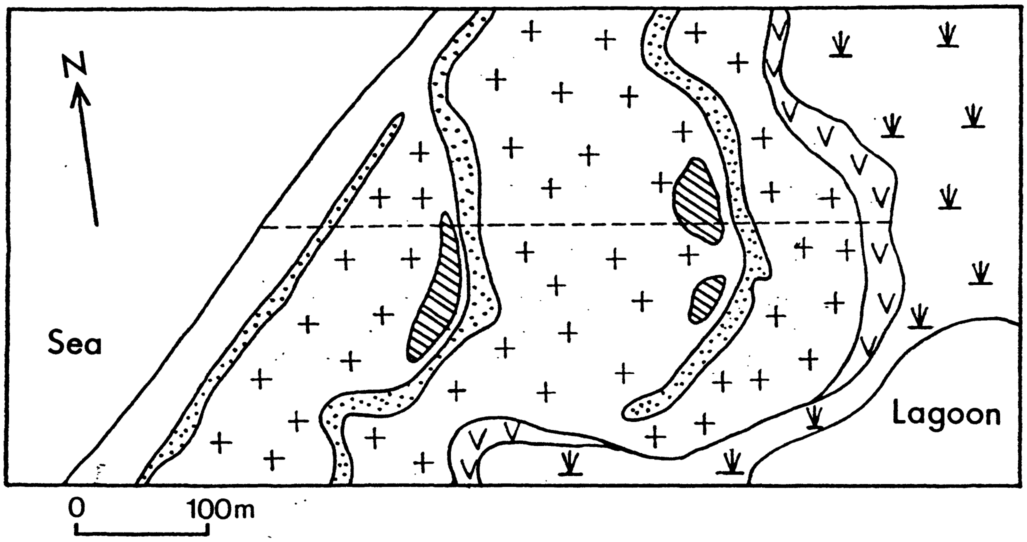


Fig. 2.2 Schematic map for Transect 1.

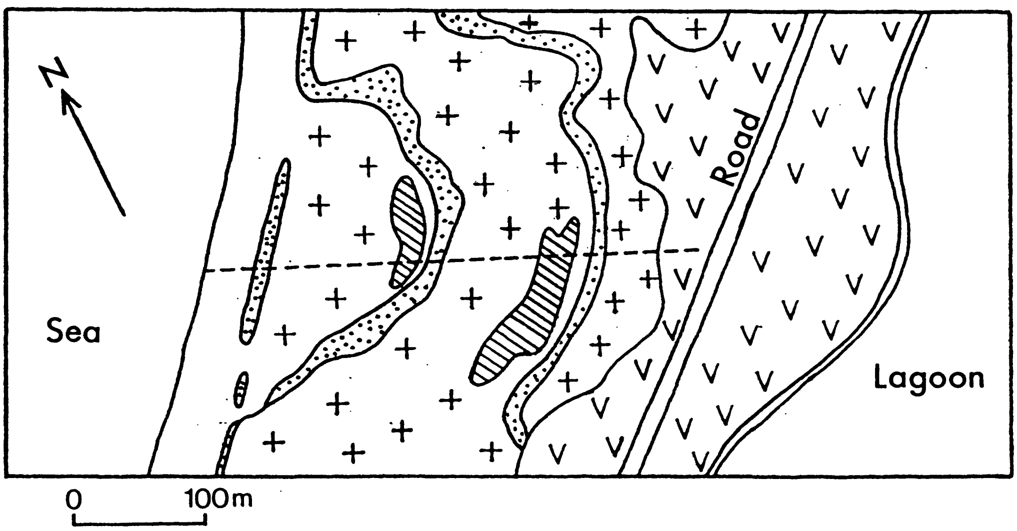


Fig. 2.3 Schematic map for Transect 2.

unvegetated, and partly covered by low density Ammophila breviligulata. In the deflation hollows at the base of the scarp faces the higher availability of groundwater supports a rich flora with a cranberry (Vaccinium macrocarpon) bog community.

2.2.2 TYPE 2: HUMMOCKY STABLE DUNES

A six kilometre sector of the west coast, north of Ile-aux-Loups, exhibits a different dune condition. The foredune is backed by older well-vegetated dunes that have undergone topographic modification. On the ground the topography appears chaotic but a series of SW-NE oriented ridges are discernible on the air photographs. Owens and McCann (1980) suggested that these ridges may represent the progradation of a spit northwards from Ile-aux-Loups during an earlier phase of the evolution of the northern tombolo.

Transect 3 (Fig. 2.4) illustrates conditions on the southern part of this coastal sector. Further north there is a broad sand flat between the foredune and the old ridges. At Transect 3 there is a narrow foredune to the west of the road and the hummocky topography of the older dunes extends 350m eastward from the road to the lagoon. The dune are highest adjacent to blowouts, most of which are now inactive. Like the parabolic dunes described above, the blowouts have been created by the dominant westerly winds and most of the sand excavated during their formation is deposited on the eastern rim.

Vegetation on the foredune is dominated by Ammophila breviligulata. On the older ridges, high cover heath vegetation predominates, except for the unvegetated blowouts and the surrounding

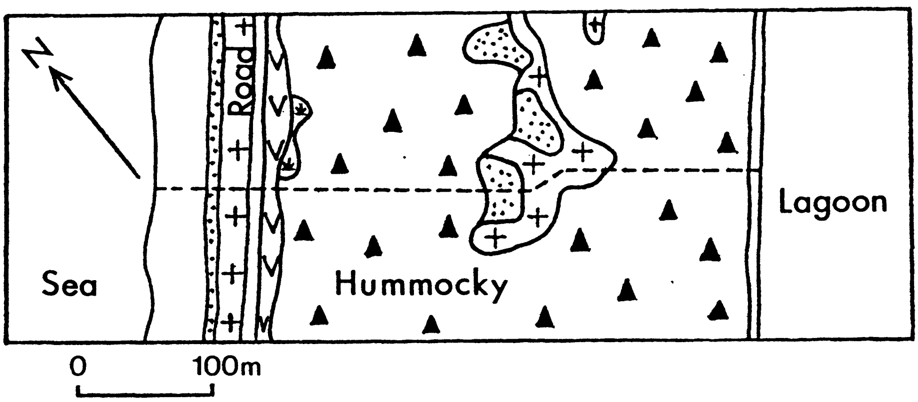


Fig. 2.4 Schematic map for Transect 3.

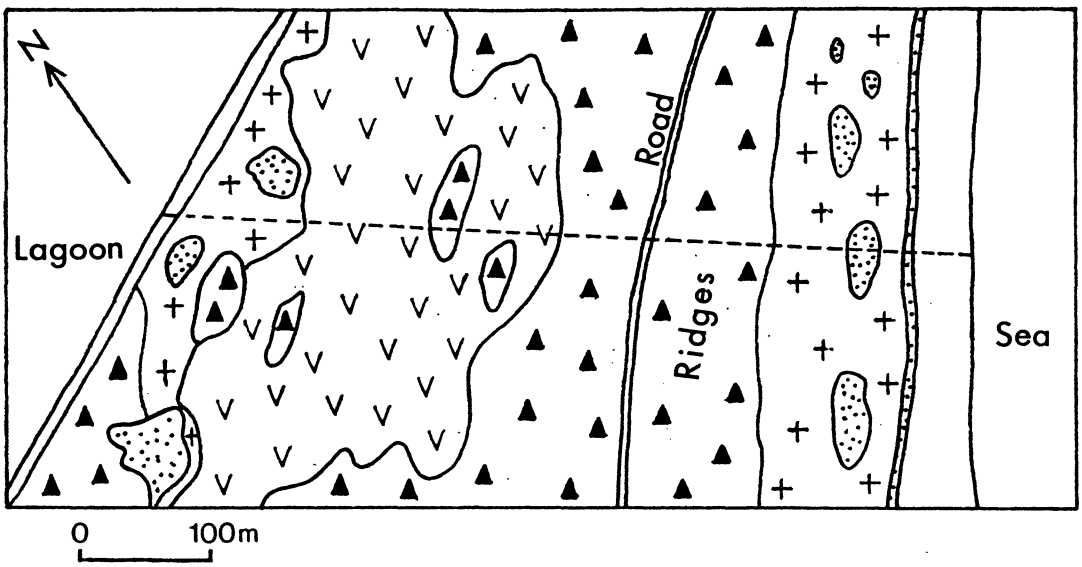


Fig. 2.5 Schematic map for Transect 4.

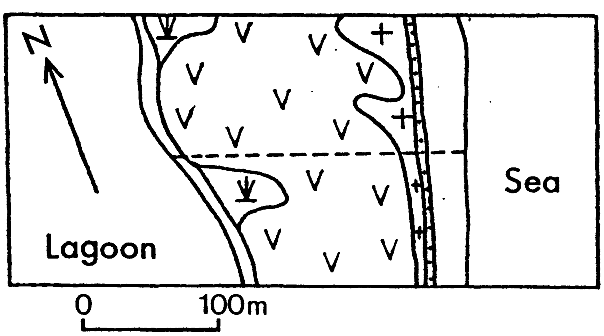


Fig. 2.6 Schematic map for Transect 5.

zone of sand deposition inhabited by Ammophila breviligulata. Inactive blowouts in various stages of recovery to heath vegetation occur in adjacent locations. The number and size of coniferous trees increases towards the lagoon and there are small, impenetrable stands of trees, one of which caused the diversion of the survey line.

2.2.3 TYPE 3: PROGRADATIONAL DUNE RIDGES

On the east coast, the southern part of Dune du Sud consists of a wide series of progradational ridges that have been deflated in places. In the vicinity of Transect 4 (Fig. 2.5), both the current foredune and a zone extending 100m inland are characterized by active blowouts and a low density vegetation cover dominated by Ammophila breviligulata. There is then a very sharp transition to the relatively stable ridge and swale topography created by progradation, with a high density vegetation cover of either heath or an Ammophila-lichen association. Occasional blowouts in the ridges have been colonized by shrubs, mainly alder (Alnus rugosa). There is an inner zone of active blowouts along the lagoon shore at Transect 4. This does not occur further south where the progradational ridges are separated by wide swales occupied by freshwater marsh (Paul 1974).

2.2.4 TYPE 4: DUNES ON RECOVERING SLUICEWAYS AND WASHOVERS

The northern half of Dune du Sud is a narrow overwashed barrier with low dunes, and it may be divided into two sectors. Towards the north, overwash processes dominate the low, flat barrier and small, vegetated dunes are short-lived features. Towards the south, overwash has been confined to wide sluiceways that are commonly closed at the seaward end by a narrow foredune. Transect 5 (Fig. 2.6) illustrates this condition, where a low foredune with the healthy Ammophila breviligulata community is succeeded inland by dune flats with dense grassland and marsh. The flats exhibit low ridges perpendicular to shore, interpreted as aeolian deposits along the margins of the former sluiceways.

The west coast also has sections where overwash processes are important. These were not investigated in great detail, but an informal survey was conducted. In comparison to the east coast Type 4 (Transect 5) dunes, the zone of active sand transport is wider and the Ammophila breviligulata community extends twice as far inland.

2.3 DESCRIPTION OF VEGETATION COMMUNITIES

A brief description of the vegetation communities shown on Figs. 2.2-2.6 now follows. This subdivision of the vegetation into communities is subjective. Dominant plants are listed here; other plants occurred less frequently and covered less area (see complete list in Appendix 3). Marsh areas were excluded from the surveys, therefore marsh is not part of this description of dune vegetation.

2.3.1 AMMOPHILA BREVILIGULATA DOMINATED COMMUNITY

This is the vegetation community found on dunes that have active sand transport, and it exhibits low to moderate cover. Ammophila breviligulata very often grows in the absence of other species, particularly nearer the sea or on dune crests. Where other species are found, the coverage is usually minor compared to Ammophila breviligulata. Cakile edentula, Honkenya peploides, and Lathyrus maritimus are members of this community but are usually restricted to the foredune. Further inland, other plants that are found include Myrica pensylvanica, Artemesia stelleriana, Solidago sempervirens, Juncus balticus, and Rosa virginiana.

The Ammophila breviligulata community covers most of the Type 1 (west coast) dunes, including the foredunes, parabolic dunes, and swales except where the bogs lie. It is also found on the foredunes and blown out parts of Transects 3, 4 and 5.

2.3.2 GRASSLAND COMMUNITY

A more diverse, moderate to high cover community is the relatively stable grassland. Ammophila breviligulata may be associated with this community, but it is not dominant as in the previous case. Other species account for much greater shares of the coverage, including Festuca rubra, Poa pratensis, Myrica pensylvanica, Empetrum nigrum, Cornus canadensis, Vagnera stellata, Achillea lanulosa, and Potentilla tridentata. Drier areas that are covered by the grassland community typically have only moderate coverage, and lichen (Cladonia alpestris) and moss (Tortella tortuosa) are frequent. Grassland vegetation covers large proportions of the dunes on the east coast, as well as some parts well inland on the west coast.

2.3.3 CRANBERRY BOG COMMUNITY

The cranberry bog community is located in the deflation hollows at the bases of the parabolic dune scarps on the west coast. These are islands of diverse flora with complete coverage surrounded by the *Ammophila breviligulata* community. *Vaccinium macrocarpon* is the principal species in terms of coverage. In the wetter bogs, mosses (*Sphagnum* sp., *Scapania* sp., *Amblystegium serpens*) are abundant, in addition to *Drosera rotundifolia* and *Iris versicolor*. Drier areas, including a transition ring around the bog, are characterized by *Juncus balticus*, *Lysimachia terrestris*, *Lycopus uniflorus*, and *Tortella tortuosa* along with the *Vaccinium macrocarpon*. One zone on the hummocky dunes (west coast) was also observed to have *Vaccinium macrocarpon* as part of the recovering heath located in the deflation hollow of an inactive blowout.

2.3.4 HEATH COMMUNITY

Progradational ridges on the northern tombolo are inhabited by a heath community that has generally complete coverage. Four species- *Empetrum nigrum*, *Arctostaphylos uva-ursi*, *Juniperus communis*, and *Juniperus horizontalis* are dominant. *Myrica pensylvanica* is also common, and *Hudsonia tomentosa* is found on recovering blowout surfaces. Other charcteristic species of the heath are *Vaccinium angustifolium*, *Trientalis borealis*, *Cladonia alpestris*, and *Potentilla tridentata*. In the most stabilized and protected areas, coniferous trees (*Picea rubens* and *Pinus banksiana*) form dense stands and exclude most other species. The height and frequency of these trees increases landward on Transects 3 (west coast) and 4 (east coast).

CHAPTER 3

DETAILED DISCUSSION OF MORPHO-ECOLOGICAL CONDITIONS

3.1 INTRODUCTION

Using the detailed morphological and ecological data collected on the northern tombolo, the differences in dune character on the west and east coasts of Les Iles-de-la-Madeleine will be shown. Dune heights given in the text refer to the immediate relief of the dune in relation to its surroundings. Conclusions will be drawn in the next chapter about the controls of wave energy and wind regime on dune character from the evidence given in the present and previous chapters.

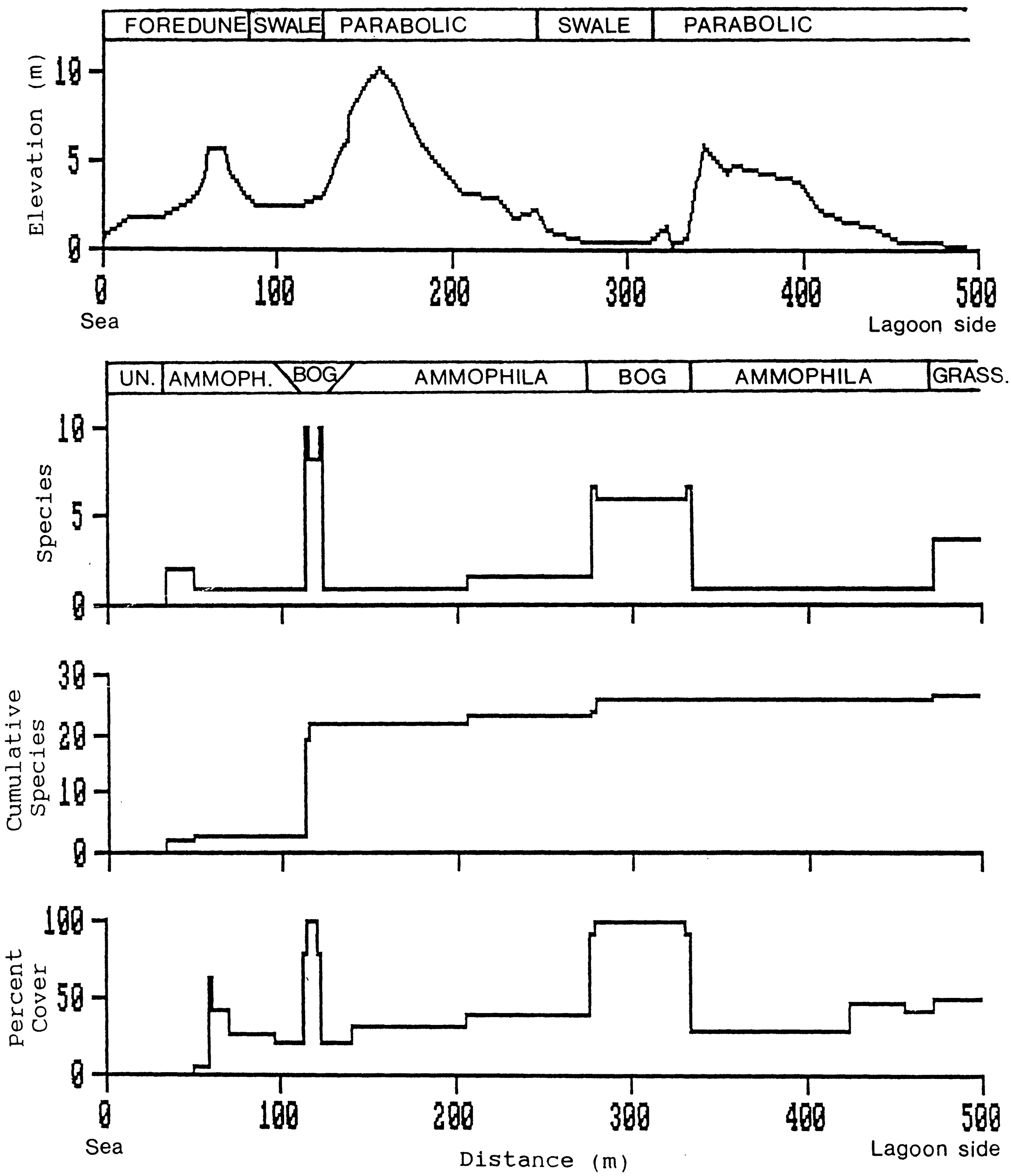
3.2 DUNE DU NORD - WEST COAST

3.2.1 TRANSECT 1

This 500m transect crosses three major features- the foredune and two parabolic dunes- and two cranberry bogs (see Fig. 3.1). The foredune is 5m high and partially blown out. On the seaward side it has a 1.5m scarp and sparsely vegetated ramp. Surrounding the foredune is the first parabolic, 7.5m high at the survey point. It is 300m in circumference, 100m wide and the seaward (slip) face steepness is 15°. The second parabolic is more spread out than the first, as shown by its dimensions: height- 5.5m, circumference- 350m, and width- 120m. A steeper slope was calculated for this dune: 28°. Each parabolic exhibits 2-3m of crest undulation and there are discrete zones of preferential erosion creating "pockets" in the dune face. On average, the bogs are 100m long by 25m wide. On the graphs (Fig. 3.1), the bogs

Fig. 3.1 Morpho-ecological character of dunes at Transect 1.

Top to bottom:
- Morphological profile (V.E. 10)
- Species richness
- Cumulative species
- Percent vegetation cover



and surrounding rings stand out as species rich, high cover zones. It is in these restricted areas that most species are encountered for the first time on the transect. In addition to Vaccinium macrocarpon, these two relatively wet bogs are dominated by Sphagnum sp., Scapania sp., and Amblystegium serpens (mosses).

Most of the area crossed by Transect 1 is covered by the low cover, species-poor Ammophila breviligulata community. Cakile edentula was also on the foredune seaward slope, and Carex silicea was observed in one zone inland. In all other areas- foredune crest and backslope, parabolic slopes, and swales except for in the bogs- Ammophila breviligulata is the only species.

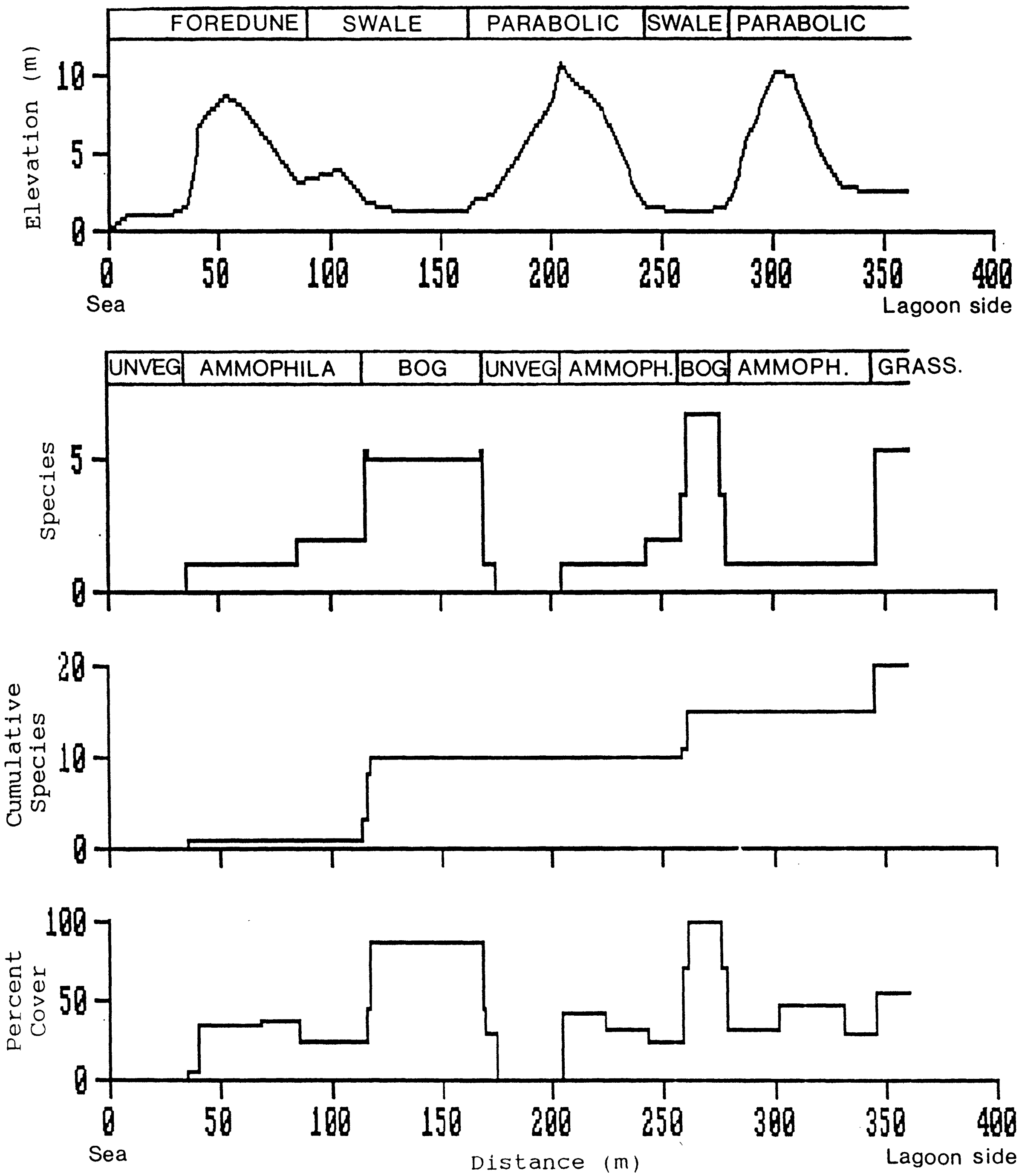
3.2.2 TRANSECT 2

Transect 2 is very similar in character to the previous example, although the corresponding features are crossed within 350m. The 8m high foredune has a 1m scarp and uneven crestline. Behind it, the first parabolic has an extremely indented slipface due to concentrated wind erosion. It has a height of 9m, circumference of 350m, width of 75m and a 16° unvegetated slipface. The second parabolic is almost a linear feature, but there is one erosion pocket that is so advanced that it forms its own parabolic shape. At the point of measurement the dune height is also 9m, and the slipface is 21°. Although it is longer, 400m in length, the width is only 60m.

Again there are two bogs situated at the base of the parabolic faces. The most significant difference in comparison to the Transect 1 bogs is that these are much drier, especially the seaward one. Thus

Fig. 3.2 Morpho-ecological character of dunes at Transect 2.

Top to bottom:
Morphological profile (V.E. 6.8)
Species richness
Cumulative species
Percent vegetation cover



Juncus balticus and Tortella tortuosa are more common and the dune/bog contrast is somewhat subdued on the cumulative species graph in terms of the number of species encountered for the first time on the transect. Only Juncus balticus is found along with Ammophila breviligulata outside the bogs until a diverse grassland is reached adjacent to the road.

3.2.3 TRANSECT 3

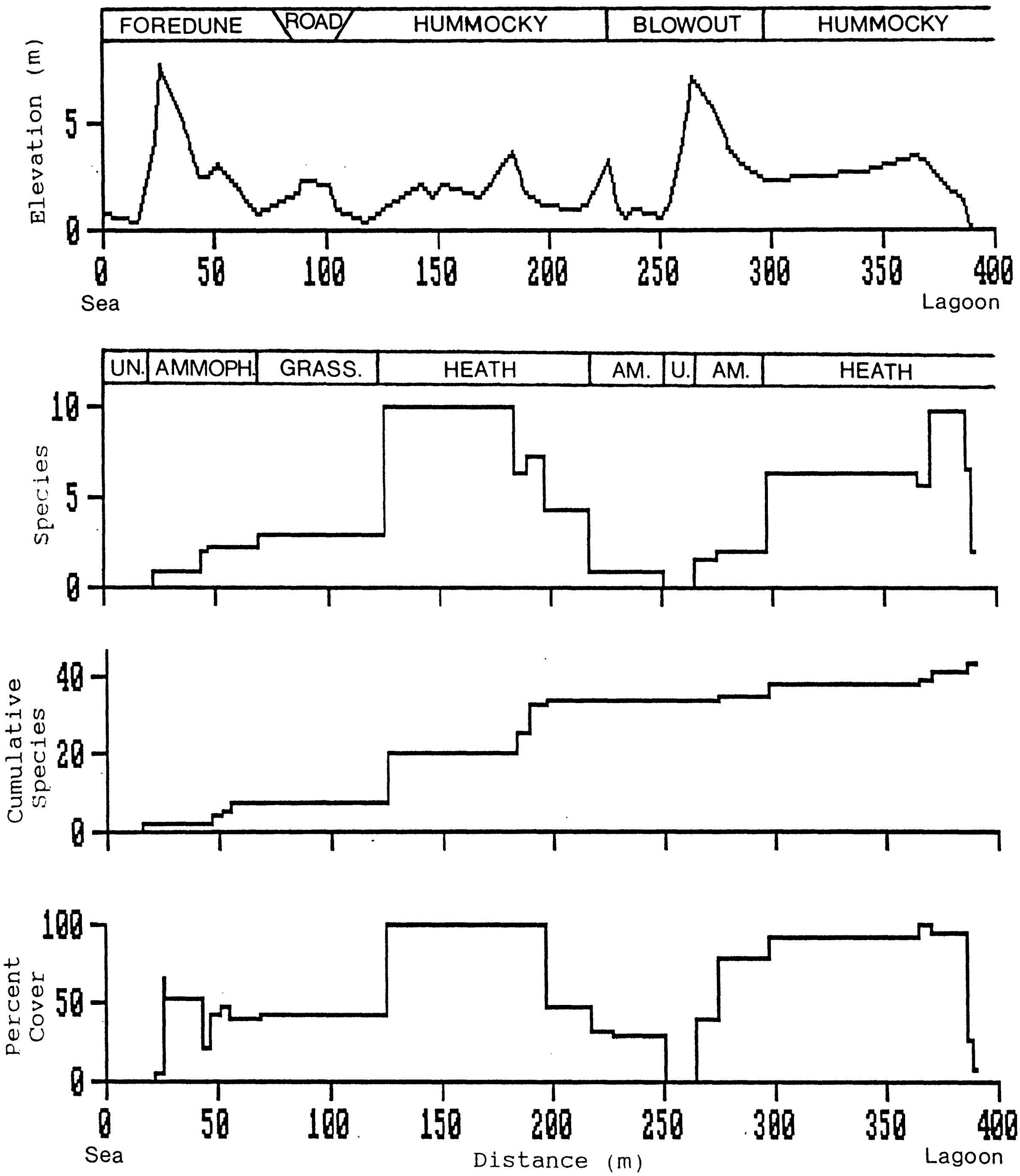
At Transect 3 (400m long) the highly mobile dunes characteristic of the west coast are replaced by hummocky stable dunes. West of the road is the active zone, only 50m wide, composed of the foredune (7.5m high) and one swale. In this section the foredune is fairly continuous and uniform for several kilometres.

To the east of the road, two areas of heath vegetation are crossed, being separated by a circular active blowout and two more nested, recovering blowouts. The first heath covers three former ridges with 1-2m relief; the other crosses two more. Inactive blowouts rims are 3-4m high, while the contemporary blowout is 7m high and 20m in diameter.

Ammophila breviligulata is the only species living on the foredune, but in the active zone adjacent to the road Artemesia stelleriana, Lathyrus maritimus, and Solidago sempervirens are common. An Ammophila breviligulata zone is encountered again around the active blowout. The base of the blowout is mainly unvegetated with some patches of Ammophila breviligulata. On the backslope where the excavated sand is deposited, Rosa virginiana, Solidago sempervirens, and Myrica pensylvanica are part of a dense Ammophila breviligulata

Fig. 3.3 Morpho-ecological character of dunes at Transect 3.

Top to bottom:
Morphological profile (V.E. 10)
Species richness
Cumulative species
Percent vegetation cover



community.

On the heath covered hummocky dunes between the road and the blowouts, the dominant species are Empetrum nigrum and Juniperus communis. A large number of less dominant species make this a zone with 100% coverage and high species richness. A few small, low stands (5m diam.) of Picea rubens exist in the hollows of the chaotic topography. Heath vegetation is recovering on the two inactive blowouts; at present Hudsonia tomentosa dominates. Behind the blowouts each of the principal heath plants (Empetrum nigrum, Juniperus communis, and Arctostaphylos uva-ursi) covers more area and the species richness is lower until a strip beside the lagoon. Behind the blowout the Picea rubens trees are taller (> 2m) and form large impenetrable stands covering at least half the area.

3.3 DUNE DU SUD - EAST COAST

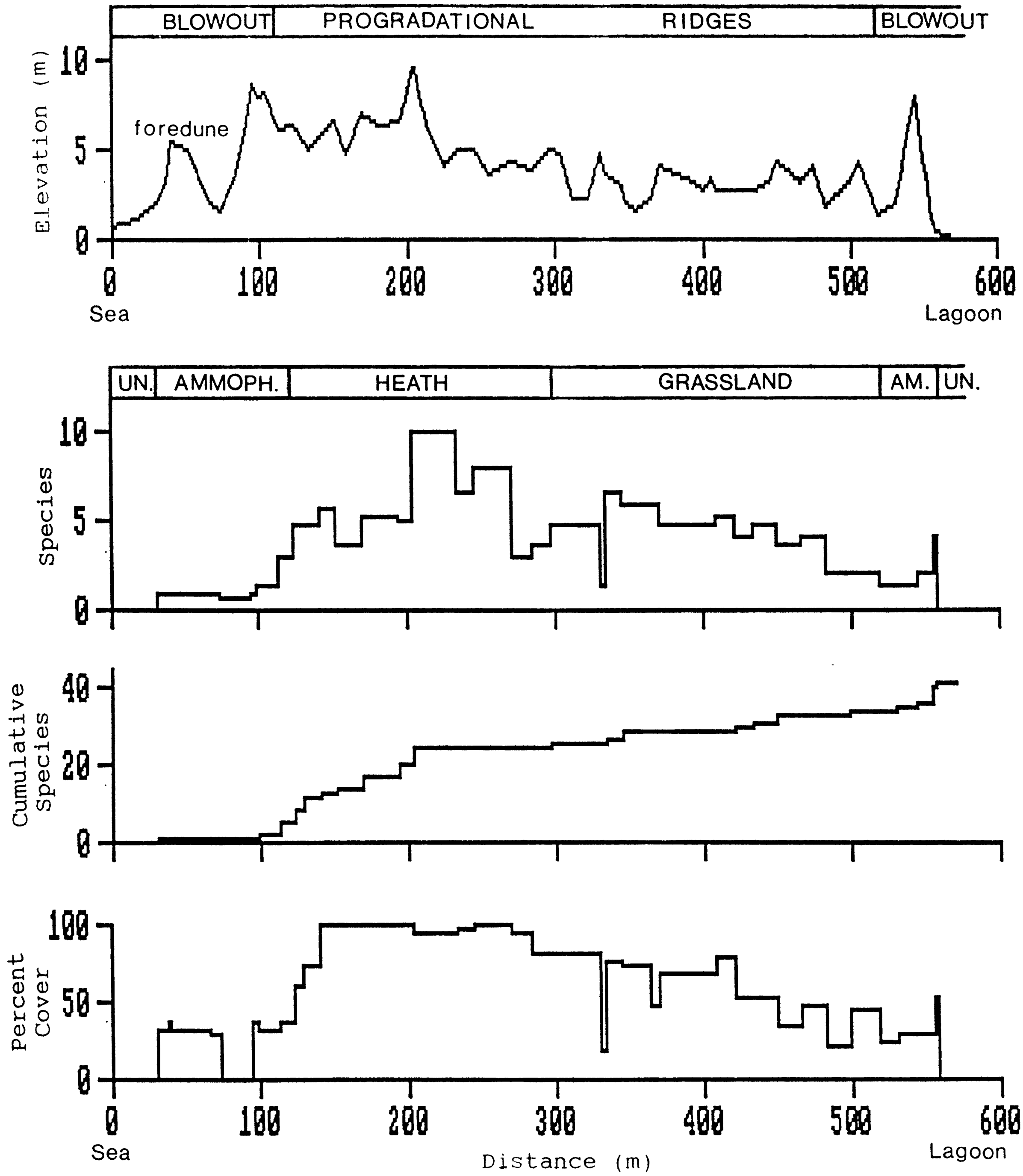
3.3.1 TRANSECT 4

At its widest point, the section of progradational ridges on the lower energy east coast is over 2km from sea to lagoon. Transect 4, 550m long, was made at the northern end of the section, and it crossed about 15 of the ridges. The first 100m of the transect consists of a 5m high foredune and a deflation blowout with an 8m high western rim. Being dug out of a coastal ridge, the blowout is a 75m X 30m hollow with a 19° steep seaward facing slope. The vegetation in this zone is the Ammophila breviligulata community, with a few more species (e.g., Myrica pensylvanica and Vagnera stellata) growing on the blowout backslope.

A very sharp transition to heath vegetation occurs at the limit

Fig. 3.4 Morpho-ecological character of dunes at Transect 4.

Top to bottom:
Morphological profile   (V.E. 12.3)
Species richness
Cumulative species
Percent vegetation cover



of landward sand transport. Before reaching the road, three 2-3m high ridges and one larger (5m high) ridge are crossed. In the swales of these ridges Picea rubens and Pinus banksiana (both < 1.5m high) dominate. On the ridges, Empetrum nigrum, Arctostaphylos uva-ursi, Juniperus communis, and Myrica pensylvanica account for most of the coverage. Beyond the road is a section of ten ridges, ranging from 1 to 3m high. The first two are covered by the heath vegetation and a stand of 2-3m high Picea rubens and Pinus banksiana.

Bordering this strip of taller trees is a transition zone on the low ridges. Heath vegetation is replaced by an unhealthy Ammophila breviligulata/Cladonia alpestris association, which is then replaced by healthy Ammophila breviligulata and Artemesia stelleriana. The reason for this is that there is a lagoon side blowout, 7.5m high, supplying sand in amounts that decrease towards the sea. On the lagoon face of the blowout the vegetation is composed chiefly of Ammophila breviligulata, Lathyrus maritimus, Artemesia stelleriana, Honkenya peploides, and Cakile edentula.

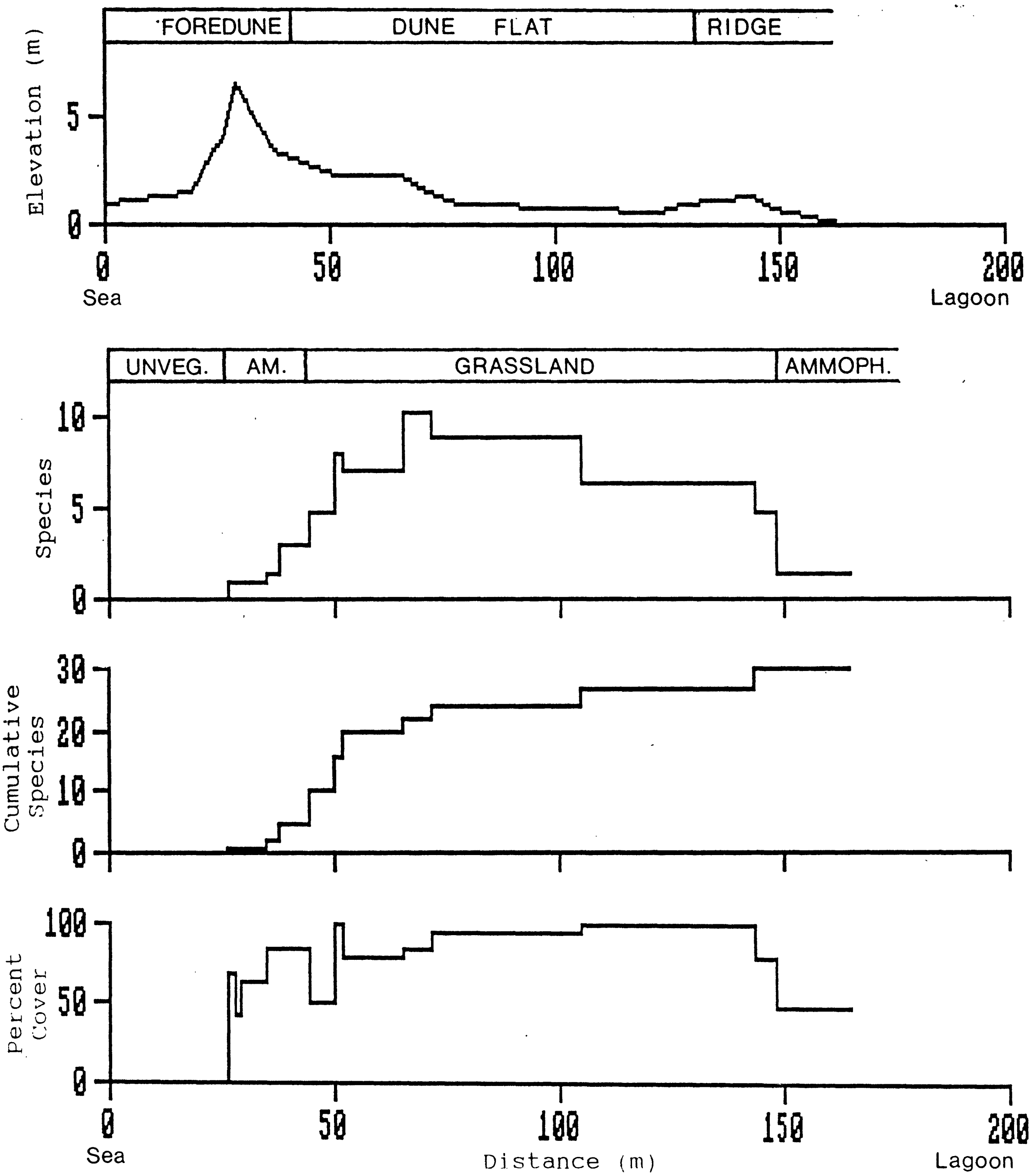
3.3.2 TRANSECT 5

Transect 5 is the shortest example (160m) and the simplest morphological profile. Apart from an adjacent, unsurveyed 3m high shore-normal ridge, the relief is provided by a 6m high foredune with no scarp. Except for openings at the former sluiceways the foredune is straight an fairly even. It is covered from crest to backslope with dense Ammophila breviligulata only.

On the lower backslope, a species-rich, high cover grassland is

Fig. 3.5 Morpho-ecological character of dunes at Transect 5.

Top to bottom:
Morphological profile (V.E. 5)
Species richness
Cumulative species
Percent vegetation cover



soon encountered, less than 50m from the water's edge. Large areas are covered by Cornus canadensis, Empetrum nigrum, and Cladonia alpestris, virtually eliminating Ammophila breviligulata. Such stable vegetation in this location indicates the low amounts of sand and salt spray transported past the foredune. A narrow strip of Ammophila breviligulata and some salt tolerant plants (e.g., Lathyrus maritimus) lies adjacent to the lagoon on a low (< 1m high) sand ridge.

3.4 CLUSTER ANALYSIS OF VEGETATION DATA

After combining the vegetation data from the five transects into a single data matrix, cluster analysis was performed using BMDP Statistical Software (1983). The matrix dimensions were 74 species by 112 vegetation zones. These zones are, as before, areas that appeared to be of distinct vegetation cover and composition in relation to the surroundings. Data values consisted of percentage cover estimates for each species in each zone (represented by the average of the three quadrats). Two programs were run: clustering by species (P1M) and clustering by zones (P2M). Zonal cluster analysis provides locational information for the vegetation in addition to species associations. This program (P2M) begins with 112 clusters consisting of the vegetation records of each zone. The two most similar clusters are combined in each step until the number of clusters is reduced to one. Appendix 5 contains the full tree diagram for this analysis.

Fig. 3.6 and Table 3.1 provide a summary and interpretation of the tree shown in Appendix 5. Based on the species composition of the largest distinct clusters (provided in the program output), the 112

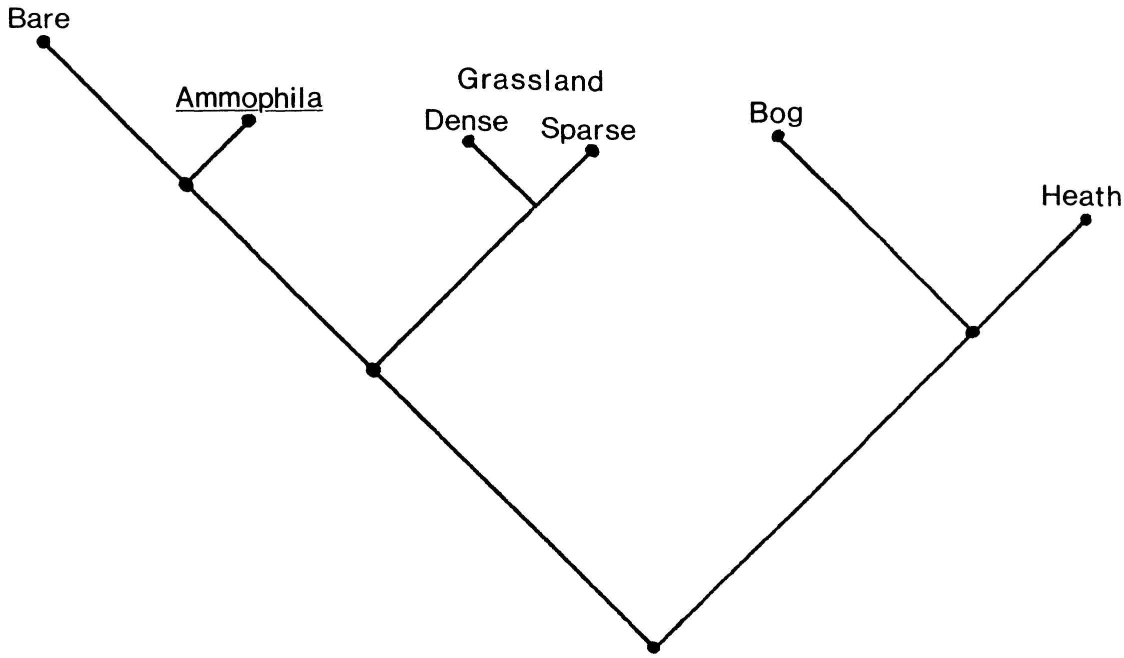


Fig. 3.6 Simplified tree diagram from zonal vegetation cluster analysis.

Table 3.1 Summary and intrepretation of cluster analysis of vegetation zones, showing the distribution of vegetation zones by community on Transects 1-5.

	Transect				
Community	T1	T2	T3	T4	T5
Bare	10%	17%	14%	8%	8%
Ammophila dominated	65	44	38	35	31
Grassland-Dense	0	6	5	10	62
Grassland-Sparse	5	17	10	20	0
Bog	20	17	5	0	0
Heath	0	0	29	28	0
No. of Zones	20	18	21	40	13

zones have been divided into vegetation categories that roughly correspond to those defined in Chapter 2 (Fig. 3.6). Each category contains a number of zones from each transect; Table 3.1 shows the distribution of each community as a percentage of the total number of zones on each transect. The length of the lines in Fig. 3.6 indicate the similarity of one cluster (shown by a dot) to other clusters in terms of vegetation composition; shorter lines connect more similar clusters.

Several parts of this analysis support the subjective vegetation classification presented earlier. The distribution of zones is consistent with the idea that the vegetation indicative of more active dunes is more common on the west coast (Transects 1, 2, and 3) than on the east coast (Transects 4 and 5). Especially noticeable in Table 3.1 are the occurrences of bog only on the west coast, heath only on Transects 3 and 4, and the dominance of *Ammophila breviligulata* on Transect 1 and of dense grassland on Transect 5. Transect 2 appears to be less dominated by *Ammophila breviligulata* zones than Transect 1; this is because slight differences in the raw data caused some zones to be included in other categories.

For the species analysis, the percentage cover of a species in all 112 zones constitutes one cluster at the start of the program. Then clusters are again combined with the next most similar cluster until only one cluster remains. The results show weak clustering: only small groups of plants (3-4 in number, maximum 7) have correlations greater than 0.4, where 1 is perfect positive correlation and 0 is no correlation. This means that the occurrence of a species at any location is not strongly indicative of a certain plant association, although some species pairs do have perfect correlation. The broad communities defined in Chapter 2 are easily identifiable, but this analysis shows that the floristic composition of the vegetation on the dunes is highly variable.

This program does not provide locational information, that is, on which transects the clusters are more likely to occur. Appendix 3, however, indicates that many species were observed only on the east coast (16) or only on the west coast (32). Of these 32, 17 species were found only in the deflation hollow bogs. Therefore, as suggested by the distribution of communities, there are differences in the flora between the two coasts.

CHAPTER 4

DISCUSSION

4.1 WEST COAST-EAST COAST DIFFERENCES

It is evident from the results presented in the preceding two chapters that an overall difference in dune character exists between coasts, although there is variability on each coast. Table 4.1 is a summary of characteristics from the vegetation survey. This table emphasizes that the vegetation on the active west coast dunes (T1 and T2) has lower species richness and lower cover, and that it is dominated to a greater extent by a single species. Heath and grassland vegetation make the stable dunes (T3, T4 and T5) richer in species and higher in coverage.

On the west coast, most of the dunes are of the large migratory parabolic type. Despite fairly long transects, the number of significant features crossed is typically three- a foredune and two parabolic dunes. Given the dimensions of the dunes, the amount of mobile sand per length of shoreline is generally much greater on the west coast than on the east coast.

North of Ile-aux-Loups, the west coast stable dunes are extensively modified remnants of former progradational ridges. Despite the high cover of rooted plants, deflation attacks these dunes and creates the complex modern topography. Migration is limited to the transgression of the foredune in this section as the heath manages to restabilize old blowouts.

In contrast, the east coast dunes are generally much less

Table 4.1 Summary of Characteristics from Vegetation Survey

Transect		Column 1	2	3	4	5
West Coast	T1	470	19	28	60	95
	T2	325	17	20	48	65
	T3	370	20	45	15	59
East Coast	T4	530	38	42	11	34
	T5	140	12	30	8	28

KEY: Column — Attribute

1 Transect length (m): vegetated part
2 Number of quadrats
3 Total number of species
4 Percentage of transect dominated by a with > 50% cover
5 Percentage of transect dominated by a single species

active. At the southern site (T4) the active dune zone is abruptly replaced by heath and grassland vegetation on multiple low progradational ridges. Some of these ridges have been deflated in places, but the extent of topographic modification is minor compared to the west coast ridges. The northern half of the east coast consists of a single dune on a narrow barrier, most of which is covered by stable grassland vegetation. By comparing this section with the parabolic dune transects, the west coast-east coast difference is very clear.

While finding differences in dune character, the similarity between Transects 3 and 4 is also recognized due to the heath vegetation and the progradational ridges. Both of these sections were formed at an earlier stage of the evolution of the tombolo when sea level was lower. Now the vegetation is still similar, but the west coast ridges are subject to greater deflation and modification than those on the east coast.

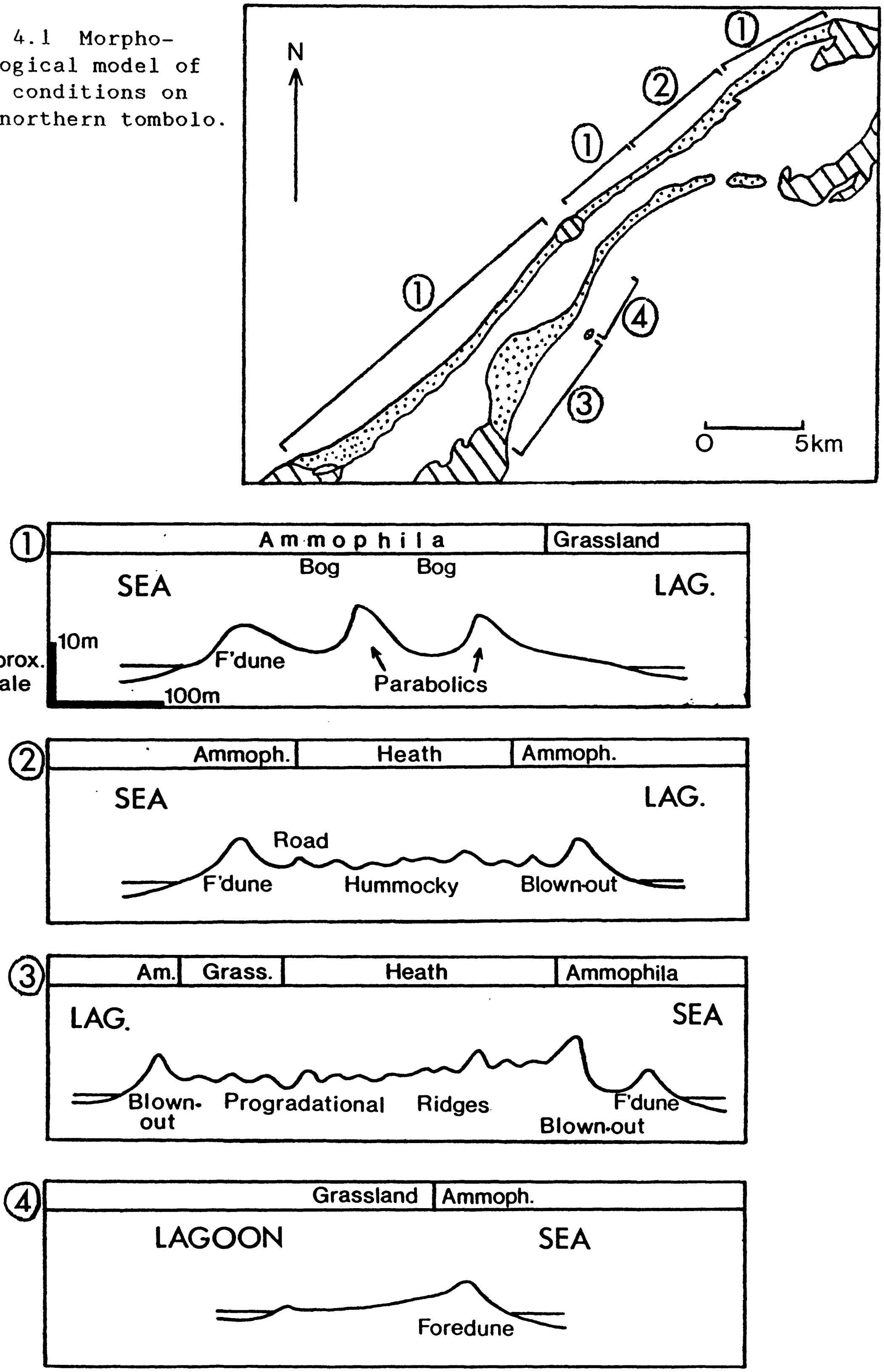
These differences in dune morphology and vegetation strongly suggest that, at the present time, much greater volumes of sand are transported from the beach to the dunes on the west coast than on the east coast. The blown-out foredune and parabolic dunes of the west coast constitute a dynamic migratory system which must be continually replenished with abundant sand from the beach and surfzone. This wide active dune system is quite different from the active dunes of the east coast. The most substantial of these are built of sand derived from the erosion and transgression of an older series of progradational ridges, rather than sand supplied from the beach and surfzone.

4.2 MORPHO-ECOLOGICAL MODEL, NORTHERN TOMBOLO

As a summary of the morpho-ecological conditions of the dunes on the northern tombolo, a simple cross-sectional model has been developed (Fig. 4.1). It consists of two prototypical diagrams for each coast-one for each of the distinctive dune types in Chapter 2. Part 1 represents most of the west coast dunes on the northern tombolo, while Parts 3 and 4 represent the two sections on the eastern coast.

The model combines the characteristic morphological features and vegetation communities in each section. Distances and associations are synthesized from the data presented in previous chapters. For the progradational ridge diagram (Part 3), the cross-section is drawn at the

Fig. 4.1 Morpho-ecological model of dune conditions on the northern tombolo.



narrow end where the transect was made. Further south the section is much wider, and wide ridge and swale topography replaces the lagoon side blowout. Unassigned sections on the map are recent overwashed areas where no surveying was done.

4.3 CONTROLLING FACTORS

Owens (1977) has shown that wave energy is 2-3 times greater on the western coast of the northern tombolo than on the eastern coast, and this results in markedly different nearshore and foreshore characteristics. It is clear from the present study that there are also differences in the backshore zone (the dunes) on the two coasts which can be attributed directly to the wave energy conditions.

Hesp (1988) argued that surfzone wave energy is a key factor affecting dune development. He suggests that higher energy results in a greater supply of sand to the beach and dunes, and also produces more salt spray which limits vegetation on the dunes to the more salt tolerant species. He indicates that blown-out foredunes are characteristic of high energy coasts from Australian examples. On Les Iles-de-la-Madeleine, wave energy causes differences in the inland dunes in addition to the foredunes.

Since the northern tombolo is only a few kilometres across, the wind regime is similar on each coast. Therefore the prevailing westerly winds are onshore on the west coast and offshore on the east coast. This factor is an important control on rates of sand supply and salt spray transport.

On Dune du Nord the prevailing winds would transfer more sand

and salt spray landward than would the subordinate easterly winds on the Dune du Sud. The effect is to enhance the differences caused by unequal wave energy levels. Plants are less smothered and less desiccated by salt spray on the east coast because of the dominant wind direction.

Another factor that explains the current state of the dunes on the northern tombolo is the pre-existing topography or evolutionary history of the dunes. This is an important reason for the stability of the hummocky dunes on the west coast, as the vegetation had stabilized before the modern dune transgression began. History also explains the wide section of stable progradational ridges that are slowly being overridden on the east coast. Without this dune complex in place, Dune du Sud would be a narrow barrier along its full length instead of just the northern half.

One other potential control on dune character- human interference- does not play a major role in the overall contrast between coasts. Human activity is most visible by the construction practices (roads, buildings and power lines) that take place on the dunes in certain areas. Localized blowouts occur where humans destroy the vegetation cover with vehicles and by repeated trampling by feet.

CHAPTER 5

CONCLUSION

5.1 CONCLUSION

Based on representative morphological and vegetation surveys, differences in character have been shown to exist between the west and east coast dunes of the northern tombolo of Les Iles-de-la-Madeleine. Sites on Dune du Nord (east coast) and Dune du Sud (east coast) have been compared using descriptive and statistical techniques. The west coast is generally comprised of a blown-out foredune and multiple parabolic dunes that are dominated by low cover (< 40%) Ammophila breviligulata, except for restricted areas of cranberry bog that occur in deflation hollows at the base of the parabolic dune scarps. A short sector of Dune du Nord consists of more stable, heath-covered dunes that are subject to modification by deflation, creating a hummocky topography.

On the east coast, the southern half of Dune du Sud is a wide series of progradational ridges. These dunes are dominated by higher cover (60-100%) grassland and heath vegetation, with a narrow blown-out zone of Ammophila breviligulata caused by the transgressing foredune overriding the seaward ridges. At the chosen study site the lagoon side is also blown-out, but this condition is not found further to the south. To the north, the barrier is narrow, with only an Ammophila breviligulata dominated foredune succeeded by high cover grassland on the dune flat. A morpho-ecological model of dune conditions on each coast synthesizes the results and illustrates the contrast in morphology and vegetation between Dune du Nord and Dune du Sud.

These differences in dune character have been related to the controls of surfzone wave energy, wind regime, and existing topography. Previous measurements by Owens (1977) showed that the wave energy is greater on the west-facing coast than on the east-facing coast. Thus, the present research is a Canadian example of Hesp's (1988) morpho-ecological model of the interaction between the surfzone conditions and foredune morphology and vegetation. The opposing orientation of the coasts to the westerly prevailing winds, and the dune forms created at earlier stages of the islands' evolution, are also important factors in determining the character of the dunes on the northern tombolo of Les Iles-de-la-Madeleine.

REFERENCES

Armon, J.W. and S.B. McCann 1979. Morphology and landward sediment transfer in a transgressive barrier island system, southern Gulf of St. Lawrence, Canada. Marine Geology 31: 333-344.

Bagnold, R.A. 1941. The physics of blown sand and desert dunes. Morrow and Co., New York.

BMDP Statistical Software 1983. W.J. Dixon, chief editor. University of California Press, Berkeley. 745pp.

Cooper, W.S. 1958. Coastal Sand Dunes of Oregon and Washington. The Geological Society of America, Memoir 72, 169pp.

Eldred, R.A. and M.A. Maun 1982. A multivariate approach to the problem of decline in vigour of Ammophila. Canadian Journal of Botany 60: 1371-1380.

Gares, P.A. 1988. Factors affecting eolian sediment transport in beach and dune environments. Journal of Coastal Research. Special Issue No. 3: 121-126.

Hesp, P.A. 1983. Morphodynamics of incipient foredunes in New South Wales, Australia. In Eolian Sediments and Processes, pp. 325-342, M.E. Brookfield and T.S. Ahlbrandt, editors. Elsevier Science Publishers, Amsterdam, The Netherlands. 660pp.

Hesp, P.A. 1988. Surfzone, beach and foredune interactions on the Australian south east coast. Journal of Coastal Research. Special Issue No. 3: 15-25.

McCann, S.B. 1979. Barrier islands in the Southern Gulf of St. Lawrence, Canada. In Barrier Islands: From the Gulf of St. Lawrence to the Gulf of Mexico, S. Leatherman, editor. Academic Press, New York. 325pp.

McLachlan, A. 1988. Dynamics of an exposed beach/dune coast, Algoa Bay, SE Africa. Journal of Coastal Research. Special Issue No. 3: 91-95.

Olson, J.S. 1958. Lake Michigan dune development 2. Plants as agents and tools in geomorphology. Journal of Geology 66: 345-351.

Orme, A.R. 1988. Coastal dunes, changing sea level and sediment budgets. Journal of Coastal Research. Special Issue No. 3: 127-129.

Owens, E.H. 1977. Temporal variations in beach and nearshore dynamics. Journal of Sedimentary Petrology 47: 168-190.

Owens, E.H. and S.B. McCann 1980. The coastal geomorphology of the Magdalen Islands, Quebec. In The Coastline of Canada, S.B. McCann, editor. Geological Survey of Canada Paper 80-10: 51-72.

Paul, L.A. 1974. Aspects of the Geomorphology of Les Iles de la Madeleine Using Remote Sensing Techniques. B.A. Thesis, McMaster University.

Pethick, J. 1984. Coastal sand dunes. In An Introduction to Coastal Geomorphology, Ch. 7. pp. 126-143. Edward Arnold, London. 260pp.

Pye, K. 1983. Coastal dunes. Progress in Physical Geography 7: 531-557.

Ranwell, D.S. 1958. Movement of vegetated sand dunes at Newborough Warren, Anglesey. Journal of Ecology 46: 83-100.

Ranwell, D.S. 1959. Newborough Warren, Anglesey I. The dune system and dune slack habitat. Journal of Ecology 47: 571-601.

Ranwell, D.S. 1960. Newborough Warren, Anglesey II. Plant associes and succession cycles of the sand dune and dune slack vegetation. Journal of Ecology 48: 117-141.

Ranwell, D.S. 1972. The Ecology of Salt Marshes and Sand Dunes. Chapman and Hall Ltd., London. 251pp.

Smith, R.L. 1980. Ecology and Field Biology, 3rd edition. Harper and Row, Toronto. 183pp.

Young, M. 1987. The vegetation of the Alexandra dunefield. M.Sc. thesis, University of Port Elizabeth. 248pp.

APPENDIX 1

Table A1.1 Mean wind direction and velocity at Grindstone, Les Iles-de-la-Madeleine, 1933-72 (from Owens (1977), Table 1, p. 171).

	Wind Direction	Wind Velocity (km/h)
January	NW	41.0
February	NW	37.2
March	NW	35.0
April	NW	33.0
May	NW	30.1
June	NW	28.7
July	SW	27.4
August	SW	28.2
September	NW	31.5
October	NW	35.7
November	NW	37.7
December	NW	40.0

APPENDIX 2

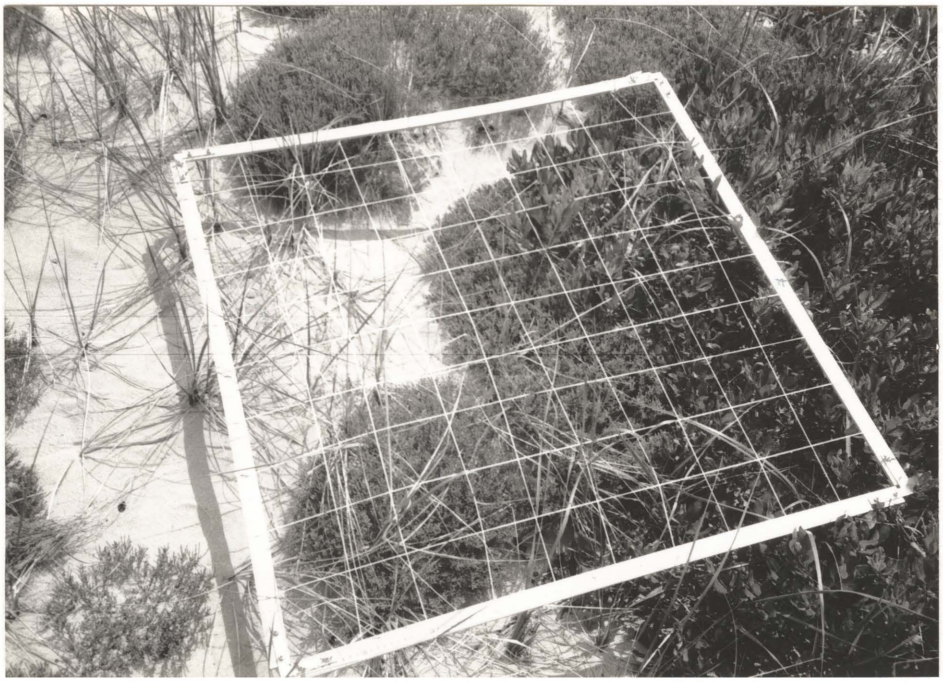


Fig. A2.1 Quadrat (1m square) used for vegetation surveying, here showing *Ammophila breviligulata* (upper left), *Hudsonia tomentosa* (center), and *Myrica pensylvanica* (lower right) on Transect 3.

Fig. A2.2 Typical low cover *Ammophila breviligulata* vegetation. Length of survey rod is 1m.

Fig. A2.3 Seawards parabolic at Transect 1, Dune du Nord (west coast). The dark patches at the base of the scarp are cranberry bogs.

Fig. A2.4 Crest and backslope of the seawards parabolic at Transect 2, Dune du Nord. The face of the second parabolic is on the right.

Fig. A2.5 Transect 3: Heath vegetation on hummocky dunes in the foreground, with the deflation blowout in the background.

Fig. A2.6 Abrupt change from the active dune zone to heath vegetation (background) on the ridges at Transect 4, Dune du Sud (east coast).

Fig. A2.7 Transect 4 (looking east): Grassland vegetation is in the foreground, heath is in the background, and Ammophila is just visible on the horizon.

Fig. A2.8 Evidence of an overridden ridge at the seaward side of Transect 4. This has been excavated by wind after erosion was initiated by people walking to the beach.

Fig. A2.9 Northern part of Dune du Sud (Transect 5): Foredune (with Ammophila) and dune flat (with dense grassland). A former sluice-way is visible in the foreground.

APPENDIX 3

Table A3.1 Species observed during vegetation surveys.

		Community			
	Coast	Ammo-phila	Grass-Land	Bog	Heath
Achillea lanulosa	B		X		
Actaea rubra	B		X		X
Alnus rugosa	B				X
Amblystegium serpens	W			X	
Ammophila breviligulata	B	X	X	X	X
Anthemis cotula	E		X		
Arctostphylos uva-ursi	B		X		X
Argentina anserina	W			X	
Artemesia stelleriana	B	X			
Aulacomnium palustre	W			X	
Cakile endulata	B	X			
Carex intumescens	W			X	
Carex montanae	W		X		
Carex scoparia	W	X			
Carex silicea	B	X			
Chrysanthemum leucanthemum	W		X		
Cladonia alpestris	B		X		X
Cladonia cristatella	E		X		
Cladonia uncialis	W				X
Convulvulus sepium	E		X		
Cornus canadensis	B		X		X
Daucus carota	E		X		
Drosera rotundifolia	W			X	
Elymus arenarius	W			X	
Empetrum nigrum	B		X	X	X
Epilobium angustifolium	E		X		X
Festuca rubra	B		X		X
Fragaria vesca	W		X		X
Gnaphalium uliginosum	E		X		
Hieracium florentinum	E			X	X
Honkenya peploides	B	X			
Hudsonia tomentosa	B		X		X
Hydrastis canadensis	W		X		X
Iris versicolor	W			X	
Juncus balticus	B	X	X	X	X
Juniperus communis	B		X		X
Juniperus horizontalis	W				X
Kalmia angustifolia	W			X	X
Kalmia polifolia	W			X	
Lathyrus martimus	B	X			X
Ledum groenlandicum	W				X
Limodorum tuberosum	W			X	
Linaria supina	W			X	

	Coast	Community: Ammophila	Grass-Land	Bog	Heath
Lonicera coerulea	W	.	.	.	X
Lycopus uniflorus	B	.	.	X	.
Lysimachia terrestris	B	.	X	X	X
Maianthenum canadense	W	.	.	.	X
Moehringia lateriflora	E	.	X	.	.
Myrica Gale	W	.	.	X	X
Myrica pensylvanica	B	X	X	X	X
Oenothera biennis	E	.	X	.	X
Picea rubens	B	.	.	.	X
Pinus banksiana	E	.	.	.	X
Plantago maritima	W	.	X	.	.
Poa pratensis	B	.	X	.	X
Polytrichum commune	W	.	.	X	.
Populus tremuloides	E	.	X	.	.
Potentilla tridentata	B	.	X	.	X
Rosa virginia	B	X	X	.	X
Rubus strigosus	E	.	X	.	.
Rumex acetosella	E	.	X	.	.
Sarracenia purpurea	W	.	.	.	X
Scapania sp.	W	.	.	X	.
Scutellaria galericulata	W	.	.	X	.
Sisyrinchium angustifolium	E	.	X	.	.
Soliadago sempervirens	B	X	X	X	X
Solidago multiradiata	B	X	X	.	X
Sonchus asper	E	.	X	.	.
Spartina patens	W	X	.	.	.
Sphagnum sp.	W	.	.	X	.
Tortella tortuosa	B	.	X	X	X
Trientalis borealis	B	.	.	.	X
Vaccinium angustifolium	B	.	.	.	X
Vaccinium macrocarpon	W	.	.	X	X
Vaccinium pennsylvanicum	B	.	X	X	X
Vagnera stellata	E	X	X	.	X
Vicia cracca	W	.	.	X	.
Vitis-idaea vitis-idaea	W	.	.	.	X
Unidentified species (10)	B	X	X	X	X

Total		
	West only	32
	East only	16
	Both	30

APPENDIX 4

Table A4.1 Morpho-ecological survey data from Transects 1-5 (summarized in graphical form in Figs. 3.1-3.5).

A Vegetation zone numbered from seaward end of transect
B Cumulative distance to midpoint of zone (m) from edge of sea
C Width of zone (m)
D Average number of species per m^2
E Average vegetation cover (%) per m^2
F Cumulative species
G Elevation (relative to lowest point on transect) at seaward boundary of zone (m)

TRANSECT 1

A	B	C	D	E	F	G
1	17	34	0	0	0	0.7
2	42	16	2	1	1	1.87
3	54.3	8.5	1	5	2	2.72
4	59.8	2.5	1	63	2	4.18
5	65.5	9	1	43	2	5.62
6	83.5	27	1	27	2	5.67
7	105	16	1	20	2	2.44
8	114	2	10	80	18	2.45
9	118	6	8.3	100	21	2.90
10	122	2	10	80	21	6.19
11	131.5	17	1	21	21	10.31
12	150	20	1	33	21	3.14
13	182.8	45.5	1	32	21	0.40
14	240.5	70	1.7	40	22	0.29
15	277	3	6.7	92	23	0.29
16	304.5	52	6	100	25	-
17	332	3	6.7	92	25	0.62
18	378.7	90.3	1	28	25	0.09
19	439.8	32	1	48	25	0.46
20	463.8	16	1	43	25	0.38
21	485.3	17	3.7	50	26	0

Zones 8 & 10 were combined in the cluster analysis.

Table A4.1 (cont.)

TRANSECT 2

A	B	C	D	E	F	G
1	17.8	35.5	0	0	0	0
2	38.3	5.5	1	5	1	1.72
3	54.8	27.5	1	35	1	6.78
4	77	17	1	38	1	6.72
5	101	28	2	23	1	3.27
6	115.5	3	2	23	3	3.94
7	142.5	1	5.3	45	8	1.77
8	143.5	51	5	88	10	2.04
9	171.5	1	5.3	45	10	2.07
10	172	5	1	30	10	2.55
11	189.7	30.4	0	0	10	10.98
12	214.4	19	1	42	10	7.83
13	233.7	19.5	1	32	10	1.53
14	250.9	15	2	23	10	1.35
15	259.9	3	3.7	72	11	-
16	268.9	15	6.7	100	15	1.49
17	277.4	2	3.7	72	15	-
18	289.9	23	1	32	15	10.42
19	316.2	29.5	1	47	15	2.84
20	338.2	14.5	1	30	15	2.72
21	352.9	15	5.3	55	20	2.69

Zones 3 & 4, 7 & 9, and 15 & 17 were combined in the cluster analysis.

Table A4.1 (cont.)

TRANSECT 3

A	B	C	D	E	F	G
1	8	16	0	0	0	0.75
2	19	6	0	0	2	0.30
3	24.1	4.1	1	5	2	3.25
4	26.6	1	1	67	2	7.63
5	33.4	12.5	1	53	2	4.12
6	41.6	4	1	53	2	2.43
7	45.1	3	2	20	2	2.43
8	49.1	5	2.3	43	4	2.99
9	53.6	4	2.3	48	5	2.60
10	62.6	14	2.3	40	7	0.84
11	97.6	56	3	42	7	0.98
12	154.4	57.5	10	100	20	3.70
13	186.4	6.5	6.3	100	26	1.65
14	193.4	7.5	7.3	100	33	1.23
15	207.1	20	4.3	47	34	1.13
16	222.1	10	1	32	34	3.27
17	239.1	24	1	30	34	0.49
18	258	13.7	0	0	34	7.07
19	269.6	9.5	1.7	40	34	5.43
20	285.8	23	2	80	35	2.25
21	331.1	67.5	6.4	92	38	3.52
22	367.6	5.5	5.7	100	39	3.00
23	378.3	16	9.7	97	41	1.29
24	387.3	2	6.7	27	44	0.24
25	389.3	2	2	8	44	0

Zones 1 & 2 were combined in the cluster analysis. Also, Zone 7 (track distrubed by vehicles) and Zones 24 & 25 were not included.

Table A4.1 (cont.)

TRANSECT 4

A	B	C	D	E	F	G
1	15.8	31.5	0	0	0	0.10
2	34.8	6.5	1	33	1	1.56
3	39	2	1	38	1	3.31
4	53.5	27	1	32	1	5.01
5	70.5	7	1	28	1	1.47
6	84.3	20.5	0.7	1	1	1.05
7	96.8	4.5	1	37	1	8.22
8	106.3	14.5	1.3	33	2	7.46
9	118.8	10.5	3	38	5	5.52
10	126.5	5	4.7	62	8	5.77
11	135	12	4.7	75	12	4.49
12	146	10	5.7	100	13	6.16
13	159.8	17.5	3.7	100	14	4.19
14	181.3	25.5	5.3	100	17	5.83
15	198.6	9.2	5	100	20	6.87
16	218.4	30.3	10	95	24	5.59
17	239.3	11.5	6.7	98	24	4.37
18	257.5	25	8	100	24	3.03
19	277	14	3	97	24	-
20	290.5	13	3.7	83	25	3.67
21	300.3	6.5	4.7	82	26	4.43
22	316.8	26.5	4.7	82	26	4.18
23	332	4	1.3	18	26	4.23
24	339.5	11	6.7	78	27	3.00
25	355	20	6	75	29	2.31
26	367.5	5	6	47	29	1.62
27	389	38	4.7	68	29	3.46
28	414.5	13	5.3	80	29	2.20
29	427.5	13	4	52	30	-
30	442.3	16.5	4.7	52	31	2.24
31	458.5	16	3.7	35	33	3.72
32	474.3	15.5	4	47	33	2.64
33	490	16	2	22	33	1.36
34	508	20	2	45	34	2.71
35	524.3	12.5	1.3	25	34	0.72
36	537.3	13.6	1.3	30	35	1.41
37	549.8	11.4	2	28	36	7.41
38	557.1	3.2	4	52	40	0.67
39	582.2	47	0	0	41	0

Cluster analysis included one zone adjacent to, but not on, profile line.

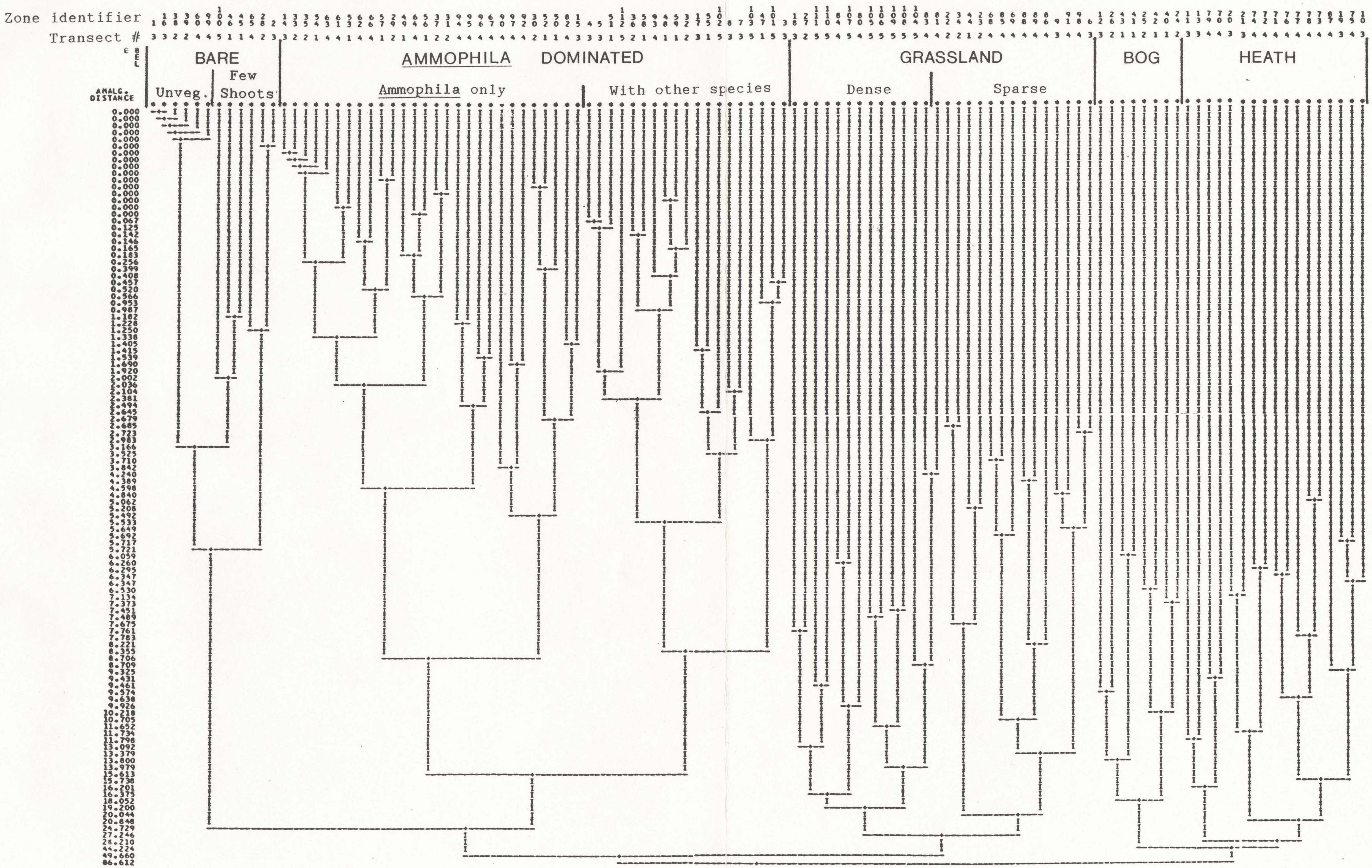
Table A4.1 (cont.)

TRANSECT 5

A	B	C	D	E	F	G
1	13.2	26.4	0	0	0	1.05
2	27.2	1.5	1	70	1	4.05
3	28.7	1.5	1	42	1	5.24
4	32.2	8.5	1	65	1	6.43
5	36.2	2.6	1.3	85	2	3.46
6	43.8	12.5	3	85	5	-
7	51	2	8	100	16	2.20
8	58.8	13.5	7	80	20	2.22
9	68.5	6	10.3	85	22	1.56
10	88	33	9	95	24	0.70
11	124	39	6.3	100	27	1.25
12	145.8	4.5	4.7	80	30	0.71
13	156.3	16.5	1.3	47	30	0

APPENDIX 5

Fig. A5.1 Tree diagram from zonal vegetation cluster analysis. Amalgamation distance is a measure of similarity between clusters when two clusters are joined.



APPENDIX 6

Table A5.1 Air photographs used in study. Source of the photographs is the National Air Photograph Library, Ottawa, Canada.

Year taken:	1969	1970
Index of set:	A21306	A21672
Photograph numbers:	Full coverage of islands	
	10-73	1-160
	Study area	
	32-53	90-130