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TIDAL IMMERSION OF THE TAMAR ESTUARY *SPARTINA* MARSH, TASMANIA, AUSTRALIA

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(with two tables, five text-figures and one plate)

ABSTRACT

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The Tamar Estuary, Tasmania, has a tidal regime transitional between semi-diurnal and diurnal with the characteristic tidal sequence being low low, low high, high low, high high. In the mature Rosevears marsh, *Spartina* covers the high tide flat sloping at 0.5° and extends down the upper third of the intertidal slope at 5.0°, to a sharply defined continuous lower limit with only isolated clumps to 0.1 m below.

During 1977 the whole marsh was immersed on all high tides, to a depth between 0.2 and 1.0 m at its upper limit. The lower limit lay at the height of the highest, high low tides but fully emerged on all low, low tides. The upper, middle and lower parts of the marsh were immersed for 1830, 3970 and 6650 hours respectively in 1977. Maximum periods of 23 hours continuous immersion of the lower edge occurred mainly in winter, resulting in non-emergence during daylight hours for up to five consecutive days. The sharp continuous lower limit may result from insufficient light under these conditions to enable buds to form to produce shoots in the following summer. Also, increasing instability in the substrate down the intertidal slope will prevent seedlings and shoots becoming firmly rooted.

INTRODUCTION

The introduction of *Spartina anglica* to the Tamar Estuary, Tasmania, in 1947, indirectly from England, and its subsequent rapid spread along a 29 km stretch of its banks was the subject of an earlier paper (Phillips 1975). *Spartina* colonized a wide variety of rock types and sediments, and slopes which varied between 1° and 28°. Previously the inter-tidal areas had been almost completely bare of vegetation, with only very limited salt marsh development in the innermost parts of the bays, close to high water mark. *Salicornia australis* was the main primary colonizer and the back of this marsh was dominated by *Phragmites, Juncus* and *Gahnia*. *Spartina* is now found within the original marsh and extending across the mud flats of the bays towards the main channel of the estuary. It also forms a fringe along the narrower stretches of the estuary. The lower edge of the most mature *Spartina* marsh has a clearly defined continuous lower limit (see plate 1), below which isolated clumps are found only occasionally down to the discontinuous lower limit. The aim of this paper is to examine the tidal relationships of this marsh.

Tidal immersion of *Spartina* has been studied in England (Ranwell *et al.* 1964; Hubbard 1969; Morley 1973), where semi-diurnal tides are experienced, although in the case of Poole Harbour, Dorset, which is the locality of the first two papers, the occurrence of a double high water twice daily modifies the simple curve. The Tamar Estuary experiences a tidal regime transitional between semi-diurnal and diurnal. Dietrich (1963) classifies it as "mixed, predominantly semi- diurnal", whereas the Admiralty (1980) defines it as diurnal but with clearly defined semi-diurnal components.

PLATE 1.- Lower edge of *Spartina* Marsh at Rosevears. High low water on 10 August, 1977 at the lower edge of an isolated clump below the continuous lower limit. The leaves and stems have died back for the winter, and form a straw-coloured thatch over the marsh surface.

TIDAL REGIME OF THE TAMAR

Continuously recording tide gauges are sited at Launceston at the head of the estuary (see figure 1) and 61 km downstream at George Town where it enters Bass Strait. At Rosevears within the central part of the estuary where *Spartina* marsh has developed, there is a tide gauge at which individual observations may be made, although records are not kept. Figure 2 shows the August 1977 tidal curve for Rosevears, which was obtained from tidal predictions for George Town given in the Admiralty Tide Tables, modified to take into account variations between George Town and Rosevears. This reveals the characteristic tidal sequence of low low, low high, high low, high high. It also shows that whilst there is generally only a small difference in height between successive high tides, there is a much greater difference between successive low tides.

Figure 3 shows the curves for two single tidal cycles, the first a spring on 4 August 1977, and the second a neap on 10 August 1977. The curves for George Town and Launceston were taken from the tide gauge charts. That for Rosevears was compiled from observations at the tide gauge there. The short winter hours of daylight prevented the recording of the complete 12½ hour cycle and part of each curve has therefore been extrapolated from the George Town and Launceston records. Comparison of the three curves for each date shows the increase in tidal range from the mouth to the head of the estuary,

producing an increasingly peaked curve towards Launceston. The later time of the tide in the same direction is also indicated, with Rosevears being 55 minutes later and Launceston 1 hour 35 minutes later than George Town on average according to the tidal predictions.

The tides experienced by the *Spartina* marsh are mainly of the type indicated at Rosevears with a small decrease in range affecting the marshes furthest down the estuary towards George Town. The maximum range on spring tides at Rosevears during 1977 was 3.9 m, and the minimum neap range was 2.1 m.

ROSEVEARS EMBAYMENT *SPARTINA* MARSH

A shallow embayment on the west shore of the estuary at Rosevears, close to the tide gauge is one of the oldest *Spartina* marshes of the Tamar (Phillips 1975). A plan and profile of this marsh are shown in figure 4. The initial plantings in the late 1940's and mid-1950's were carried out at Windermere on the east shore opposite and from here it spread rapidly both up-stream and down-stream to occupy the stretch of the estuary indicated on figure 1 by the summer of 1971-72. A series of vertical aerial surveys carried out during the 1960's revealed the details of this spread. At Rosevears *Spartina* was well established in the inner part of the embayment by 1961 and it continued to spread in this area up to 1963, by which time it had appeared also at the southern end. By 1968, *Spartina* had filled the whole embayment to straighten effectively the shore between the adjacent promontories. The straight lower edge of the marsh extended only slightly towards the channel during the following year and a field survey during the 1971-72 summer indicated that no further extension had occurred. A detailed levelling survey in January 1972 showed the height of the upper, landward margin of this marsh to be 3.1 m and the discontinuous lower limit to be 1.2 m above George Town Chart Datum. A further levelling survey carried out five years later in August 1977 showed that no change had taken place in these heights.

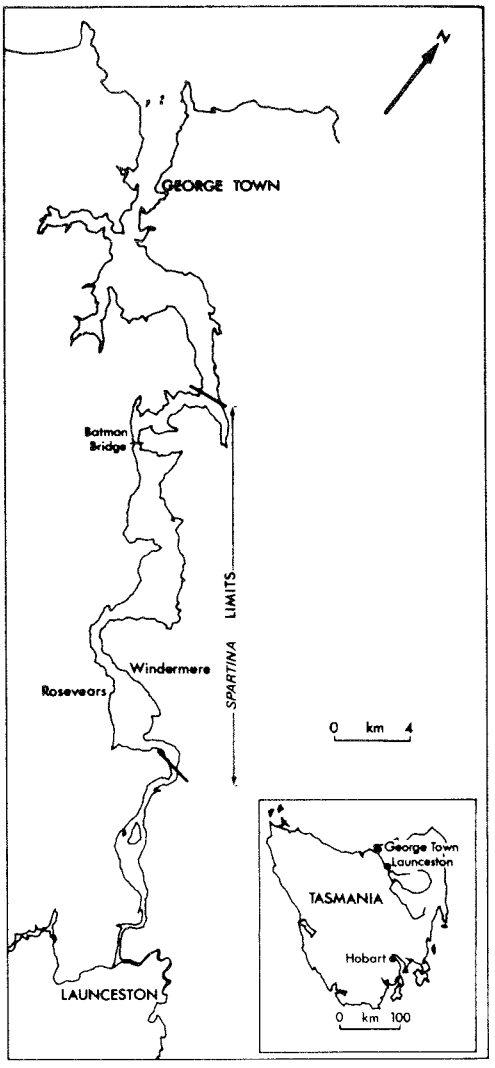


FIG. 1.- Location map.

Because the ground rises abruptly behind the upper margin of the marsh, no extension is possible in this direction. Below the lower edge of the marsh, however, there is an area of bare mud bank exposed down to extreme low water mark. The stable position of this margin since 1969 with its well marked continuous lower limit indicates that some factor or combination of factors is exerting a strong, limiting control.

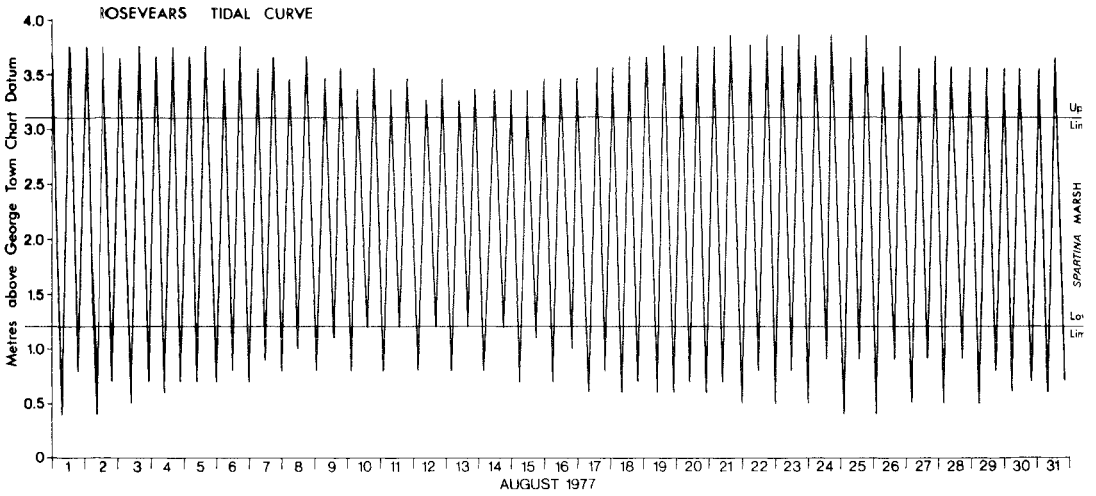


FIG. 2.- Rosevears tidal curve for August 1977. Admiralty tidal predictions for George Town were modified as follows to obtain data for Rosevears:
Times: + 0h 55 min (from Port of Launceston Tidal Predictions for George Town)
Heights: + 0.45 m for high high water and low high water
+ 0.10 m for high low water and low low water (from observations at the Rosevears tide gauge).

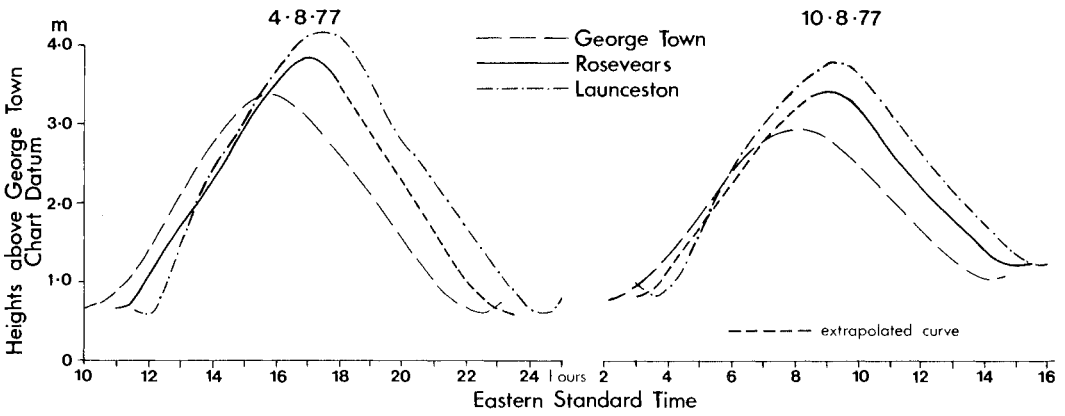
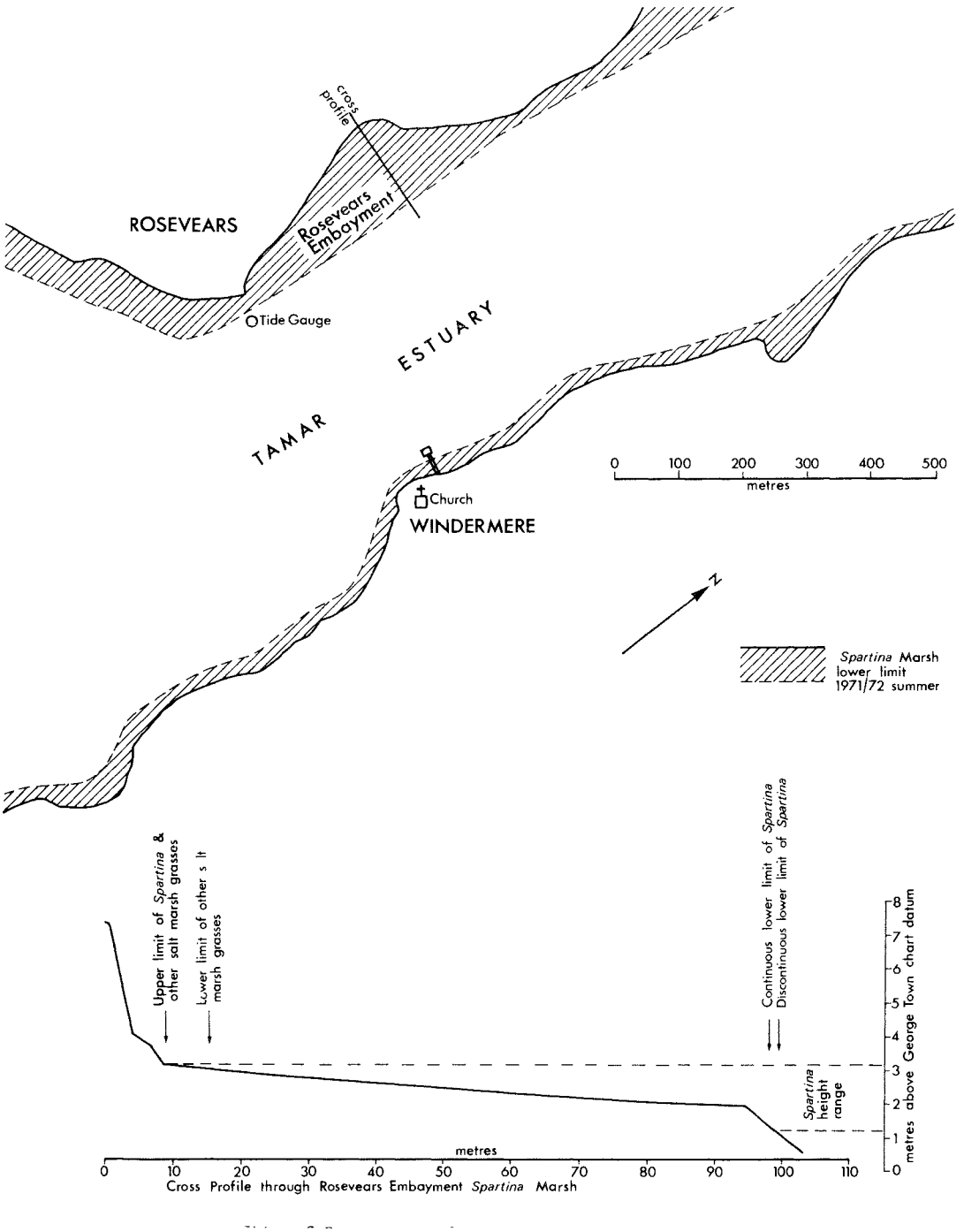


FIG. 3.- Tidal Curves for George Town, Rosevears and Launceston on 4.8.77 and 10.8.77. These were constructed from tidal records, except for the extrapolated sections of the Rosevears curves when darkness prevented recording.


ROSEVEARS
Rosevears Embayment
cross profile
Tide Gauge
ESTUARY
TAMAR
Church
WINDERMERE
0 100 200 300 400 500
metres
N
Spartina Marsh lower limit 1971/72 summer
Upper limit of Spartina & other salt marsh grasses
Lower limit of other s lt marsh grasses
Continuous lower limit of Spartina
Discontinuous lower limit of Spartina
Spartina height range
metres above George Town chart datum
0 1 2 3 4 5 6 7 8
metres
0 10 20 30 40 50 60 70 80 90 100 110
Cross Profile through Rosevears Embayment Spartina Marsh

TIDAL RELATIONSHIPS OF THE ROSEVEARS MARSH

Inserted on figure 2, which shows the Rosevears tidal curve for August 1977 are the upper and lower limits of the *Spartina* marsh. These levels refer to the surface of the substrate in which the *Spartina* is growing. During the summer the plants grow to a height of up to 1.5 m above this, but in the winter the leaves and stems die back to produce a lower straw-coloured thatch over the marsh surface as shown in plate 1, and the only living parts, the rhizomes and roots are below the surface of the substrate. Monthly curves similar to that for August have been drawn for the whole of 1977, using the tidal predictions for George Town and making appropriate adjustments for Rosevears as indicated in the caption to figure 2. Details of tidal immersion and emergence of different parts of the marsh become clearly apparent from such diagrams.

Upper edge of the marsh

Table 1 shows the maximum and minimum depths to which the upper edge of the marsh was immersed each month. Especially noteworthy is the fact that the whole marsh was immersed on every high tide during the year, that is it was immersed on both high high and low high tides each day. The minimum depth of immersion, 0.2 m, was reached on between 2 and 6 tides per month during the summer periods of January-February, and November-December, and also during the winter months of August-September. The maximum depth of immersion per month was either 0.8 or 0.9 m except for two very high tides in May which produced a 1.0 m immersion. As the *Spartina* reaches a height of about 1.5 m during the summer growing period the plants here were never totally immersed then.

TABLE 1

TIDAL IMMERSION OF UPPER MARSH EDGE AT HIGH WATER
- ROSEVEARS EMBAYMENT

1977	Maximum depth m	Number of tides	Minimum depth m	Number of tides
January	0.8	3	0.2	6
February	0.8	5	0.2	3
March	0.9	2	0.3	4
April	0.9	8	0.4	12
May	1.0	2	0.4	6
June	0.9	8	0.4	10
July	0.8	14	0.3	5
August	0.8	5	0.2	2
September	0.8	6	0.2	2
October	0.8	8	0.3	11
November	0.9	1	0.2	2
December	0.8	5	0.2	4

Notes: (a) The height of the upper marsh edge in 1977 was 3.1 m George Town Chart Datum.

(b) The maximum depth of submergence with the number of tides producing this, and also the minimum depth of submergence with the number of occurrences was taken from the Rosevears monthly tidal curves, e.g. figure 2 for August 1977.

Lower edge of the marsh

The lower edge of the Rosevears marsh emerged at all low low tides. Table 2 shows the minimum emergence per month at high, low tides. Only during the four months of February, March, September and October was there complete emergence. During May, June and July the highest, high low tides did not fall below the continuous lower limit at 1.3 m, George Town C.D., on between 3 and 5 tides per month, thus leaving the scattered, isolated *Spartina* clumps below it immersed between successive low low tides. During these winter months when the leaves and stems are dead the only living parts of the plant are below the surface of the substrate and are thus totally immersed on such tides. During the remaining 5 months of January, April, August, November and December the highest high low tides fell to the outer edge of the isolated clumps, the discontinuous lower limit, at 1.2 m George Town C.D., on between 3 and 5 tides per month; and this was the case also on 2 or 3 tides during each of the months of May, June and July. Plate 1 shows high low water in this position on 10 August 1977.

The periods when these highest, high low waters occurred were mainly during the winter months of April to August, but some also occurred during the summer in January and November-December. It does appear that there is a close relationship between the height of these highest, high low tides and the lowest level to which the *Spartina* marsh is able to develop.

TABLE 2

MINIMUM TIDAL EMERGENCE OF LOWER MARSH EDGE AT HIGH LOW WATER - ROSEVEARS EMBAYMENT

1977	
January	4 tides at discontinuous lower limit
February	complete emergence on all tides
March	complete emergence on all tides
April	3 tides at discontinuous lower limit
May	3 tides at discontinuous lower limit; 4 tides at continuous lower limit
June	2 tides at discontinuous lower limit; 5 tides at continuous lower limit
July	3 tides at discontinuous lower limit; 3 tides at continuous lower limit
August	5 tides at discontinuous lower limit
September	complete emergence on all tides
October	complete emergence on all tides
November	3 tides at discontinuous lower limit
December	4 tides at discontinuous lower limit

Notes: (a) The continuous lower limit is the clearly defined lower edge of the mature *Spartina* marsh at a height of 1.3 m George Town Chart Datum, in 1977.

(b) The discontinuous lower limit encompasses the few isolated *Spartina* clumps below the continuous lower limit and was at a height of 1.2 m George Town Chart Datum, in 1977.

(c) The number of high low waters at the continuous lower limit, at the discontinuous lower limit, and below the latter was taken from the Rosevears monthly tidal curves, e.g. figure 2 for August 1977.

Duration of tidal immersion

The absence of continuous tide gauge records for the central part of the Tamar estuary, where the *Spartina* marsh has developed, means that precise measurements of lengths of time of tidal immersion are not possible. The tidal records for George Town for the first two weeks of March and August 1977 were used to produce approximate extrapolated curves for Rosevears from which the immersion times of different parts of the marsh were calculated. The same periods of the monthly curves for George Town were then fitted to the remainder of the 1977 monthly curves. This enabled the calculation of immersion times at Rosevears to be extended throughout 1977.

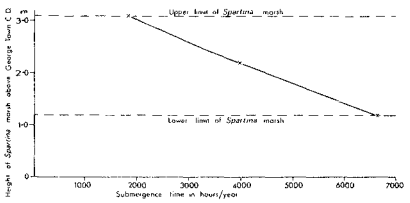


FIG. 5.- Duration of tidal immersion of Rosevears *Spartina* marsh in 1977. The times relate to the immersion of the surface of the substrate, which is the upper limit of the living parts of the plants during the winter months. During the summer growing season the leaves, stems and flowers will reach up to 1.5 m above this.

The upper edge of the marsh was immersed for a total of approximately 1830 hours, the middle for 3970 hours and the lower edge for 6650 hours during 1977 (see figure 5). The average lengths of immersion per tidal cycle for the combined periods of 1-14 March and 2-14 August were 2.6 hours (range 1-4 hours), 5.6 hours (4.5-6.5) and 9.2 hours (8.25-22) for the upper, middle and lower marsh respectively. The maximum period of continuous immersion of the extreme lower edge during the highest high low waters of 1.3 m on neap tides was approximately 23 hours out of the diurnal cycle of 25 hours. As the brief periods of emergence (with only one exception) occurred during the hours of darkness in the winter months of May, June and July, the isolated clumps of *Spartina* forming the extreme lower fringe of the marsh did not emerge during the daylight hours on three consecutive days in May and July and five consecutive days in June.

DISCUSSION

The presence in the Tamar Estuary of extensive areas of previously bare inter-tidal mud flats and the particular tidal regime described, clearly provided an ideal ecological niche for the introduction of the exotic species *Spartina anglica*. Its rapid spread, usually from an initial position close to high water mark, appears to meet no barrier in its advance towards the main channel of the estuary until it reaches the level of the highest high low tides.

Davies (1980) divided the morphology of tidal flats in coastal inlets into the high tide flat below which lies the intertidal slope. The high tide flat is relatively stable and vegetated whilst the intertidal slope is characterized by considerable instability with alternate deposition and erosion creating conditions generally unfavourable to plant growth. The junction between the two slope elements is convex. These morphological elements can be seen clearly in the Rosevears marsh profile (figure 4) with the high tide flat sloping at only 0.5° whereas the angle of the intertidal slope is 5.0°. *Spartina* grows to the upper margin of the high tide flat and almost certainly would be capable of growing at a higher level in relation to High Water Mark, as the entire marsh is immersed on all high tides and is under a considerable depth of water at spring tides. However the *Spartina* is prevented from spreading landwards by the steeply rising ground, already colonized by fresh-water vegetation. Rapid accretion by sedimentation did occur on the high tide flat during the earlier stages of *Spartina* colonization and this was shown by the presence of *Spartina* remains to a depth of 2.29 m beneath the surface in 1972 (Phillips 1975). However there was no evidence of accretion continuing between 1972 and 1977. The main source of sediment for the earlier accretion was probably the extensive mud flats of Nelsons Shoal upstream from Windermere which by the early 1970's was

colonized by the largest continuing area of *Spartina* in the Tamar Estuary thus effectively trapping the previously more mobile sediment.

The lower limit of *Spartina* growth does not coincide with the clearly defined convex junction between the high tide flat and the intertidal slope, but is over a third of the way down the intertidal slope towards its lower boundary at Low Low Water Spring Tide Mark, the extreme level of which was 0.1 m George Town Chart Datum in 1977. The position of the convex slope junction is generally controlled by sedimentation and channel regimes and it appears therefore that there is some other factor or combination of factors controlling the lower limit of *Spartina*. The fact that this lower limit coincides with the height of the highest, high low tides may point to a significant relationship. As Hubbard stated the tidal immersion of a marsh may alter many of the environmental conditions within the habitat, including moisture content, salinity, aeration, light intensity and duration, and temperature. It also produces such physical changes as intermittently present wave and current action.

The closest comparable published data on a *Spartina* marsh is that relating to Poole Harbour, Dorset. Ranwell *et al.* (1964) gave the tidal immersion limit there for *Spartina* as 5800 hours/year which is 87% of the annual immersion time of 6650 hours for the lower edge of the Rosevears marsh. Hubbard (1969) after inspecting a year's tide gauge records from Poole Bridge, determined that on the highest low water on a neap tide in November the lowest level of the Poole Harbour marsh was continuously immersed for 23½ hours. This is similar to the figure for the Rosevears marsh on the highest high low waters between May and July. As buds developing in November produce shoots for the following summer growing season, Hubbard suggested that the amount of light reaching *Spartina* at this time of year is critical for its survival. This may be the reason for the lower limit of the Rosevears *Spartina* at a level where several consecutive days with no daylight emergence are experienced during the equivalent southern hemisphere month of May and the two subsequent months.

As there is very little cliffing along the continuous lower limit of the Tamar marshes and as only very small waves are able to develop in the narrow confines of the estuary it does not appear that exposure to wave attack limits their lower extension. The lowest edge of these marshes is closest to the main channel in which the tidal streams reach their maximum velocities. Sedimentary conditions on the adjacent parts of the inter-tidal slopes become increasingly unstable towards the channel and this may be a further limiting factor, preventing seedlings and shoots becoming firmly rooted. The sharpness of the continuous lower limit probably results from the steepness of the intertidal slope and therefore the rapidity of change in the length of tidal inundation which itself influences the wide range of environmental conditions referred to.

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