MARINE BIOLOGY OF MILFORD HAVEN: THE PHYSICAL ENVIRONMENT

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INTRODUCTION

MILFORD HAVEN is situated at the south-western extremity of Wales (Fig. 1), at the junction of the Bristol Channel and St. George's Channel. The deep and land-locked waters of the lower estuary offer a sheltered natural harbour for vessels of all sizes, and coastal traffic in agricultural produce and anthracite from the South Pembrokeshire coalfield (Edwards, 1963; George, 1964) was once considerable. The growth of Milford, Neyland and Pembroke Dock has been described in detail by Gilpin (1960).

Large-scale commercial exploitation of the estuary has been hampered until recently by its remote position, but after the Second World War a search for ports capable of accommodating tankers and bulk carriers of up to 100,000 tons capacity revealed that Milford Haven was one of the very few suitable sites in the British Isles. By 1965 three tanker-terminals have been built, two serving adjacent oil refineries and the other a refinery near Swansea by an overland pipeline, and the construction of a large oil-fired electricity generating station has begun at the mouth of the Pembroke River. Further industrialization is likely to follow and cannot fail to alter a hitherto very "unspoilt" estuary.

The mouth of the Haven forms part of a rocky coastline bathed by clean, oceanic water in a region where the ranges of predominantly southern and Arctic forms overlap. The marine flora and fauna is therefore one of the most varied in the British Isles. Because of the deep and rocky nature of Milford Haven and the Daucleddau this variety extends far up the estuary. Almost all

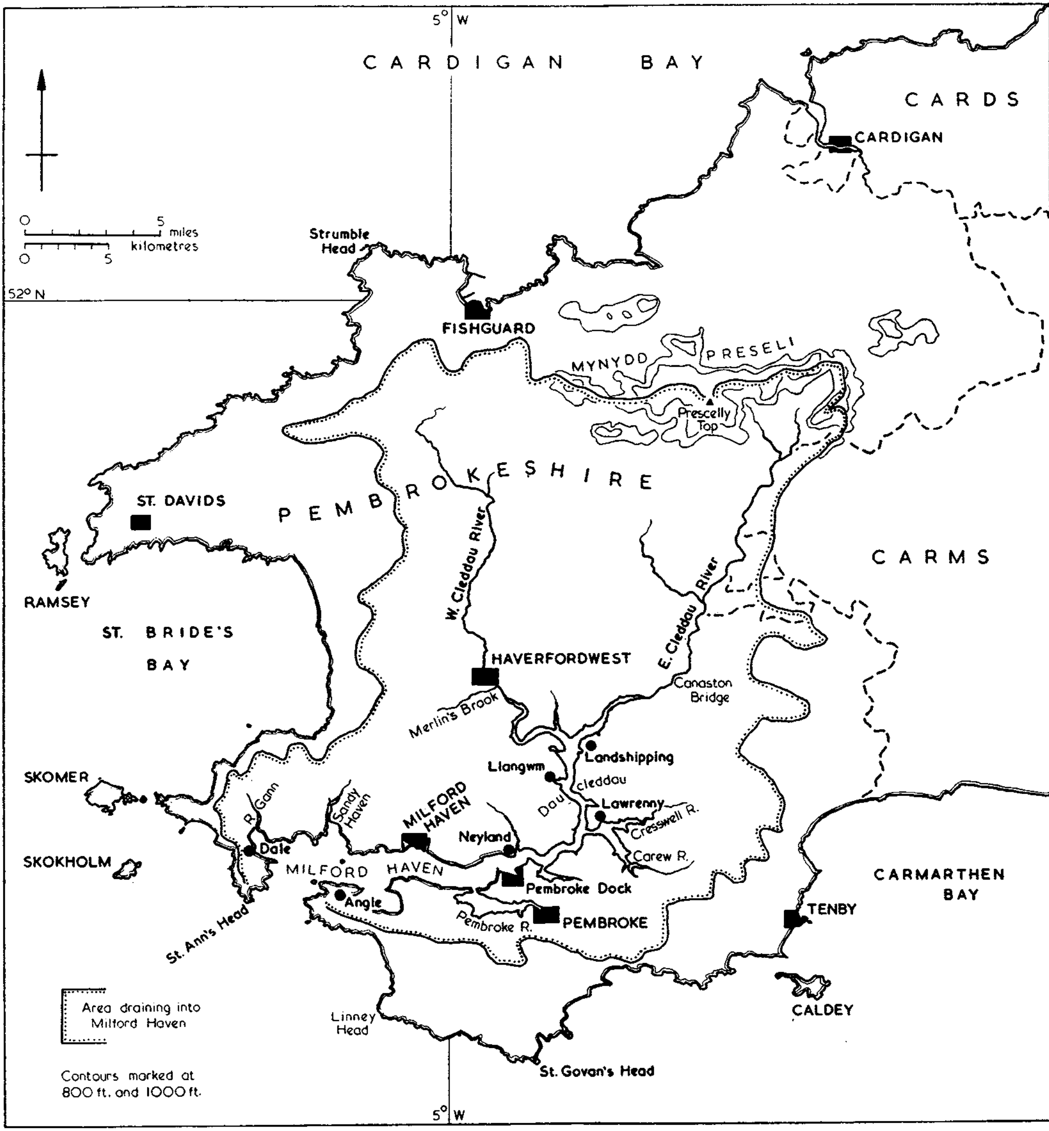

FIG. 1.

South-west Wales, showing Milford Haven and its approximate catchment area.

the published accounts of its marine biology are concerned with the neighbourhood of Dale Fort Field Centre, in the mouth (see Moyse and Nelson-Smith, 1963; and Crothers, in press). A number of surveys which include the upper reaches were made by staff of the Ministry of Agriculture, Fisheries and Food, although only one of their reports has been published (Cole, 1953). The present study was started during the earliest stages of the industrialization of Milford Haven, and consists primarily of a careful survey of the distribution of common species of plants and animals which inhabit rocky shores throughout the estuary. This first section outlines those physical characteristics of the environment which are important to the marine flora and fauna, and incorporates many data collected by other investigators concerned with the development of the Haven. Later contributions will deal with the distribution both of littoral and sublittoral species within the Haven. A preliminary account of the local race of herring which spawns in the upper reaches has already been given (Nelson-Smith, 1964).

I. Structure

The estuary is a ria cut in the 200 ft. erosion platform of South Pembrokeshire and drowned in post-Glacial times. Milford Haven proper is virtually an inlet of the sea, extending from Dale Roads eastwards to Pembroke Dockyard and protected to the west by the Dale peninsula. A wide, relatively shallow entrance opens to the south-west. The Daucleddau, or common estuary of the rivers Cleddau, takes up a northerly direction between Neyland and Picton Point (Fig. 1). Some typical sectional profiles of the estuary are given in Fig. 2. The mean volume of the Haven (to mid-tide level) between Thorn Island and Picton Point was calculated from a series of such sections as 53,000 million gallons (240,500 million litres).

The lower stretches of the rivers Cleddau pass across the South Pembrokeshire coalfield, but below Llangwm the rock is nearly all Old Red Sandstone. Angle Bay, the Pembroke River and Cosheston Pill pass through this into the carboniferous limestone which lies to the south.

II. The shores and bottom

Rocky or stony shores occur throughout the length of Milford Haven and the Daucleddau, interspersed with extensive banks of mud or muddy gravel. Fig. 3 shows the general nature of the coastline and shores of the Haven. The nature of the bottom deposits is indicated on Admiralty charts and has been investigated by the Hydraulics Research Station (1958) and by Posford, Pavry and Partners (1959).

Around the mouth the coastline is generally of high rocky cliffs skirted by eroded reefs and boulders in exposed localities, and by beaches of smaller stones or clean sand in the bays. The nature of the shore closely reflects its degree of exposure to wind and waves; the very sheltered flats at the mouth of the River Gann have patches of mud and muddy sand (Bassindale and Clark, 1960). Profiles of selected shores around the Dale peninsula are given by Moyse and Nelson-Smith (1963). Further to the east, the headlands directly facing the entrance to the Haven are fairly high, steep and exposed. South Hook Point and Thorn Point are lower and more protected by reefs and boulders, and rocky reefs are well developed in Sandy Haven and West Angle Bay (just south of

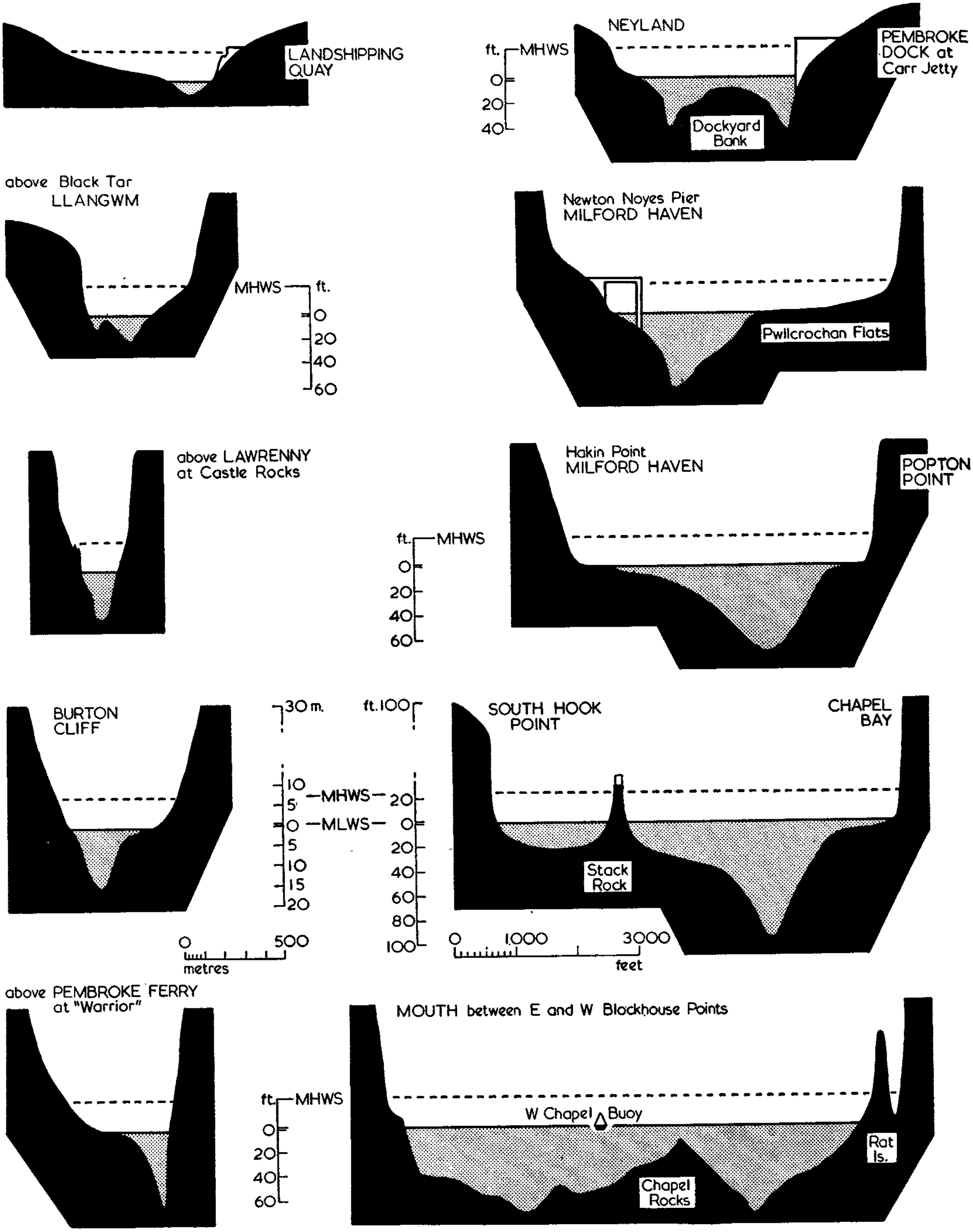

FIG. 2.

Sectional profiles of Milford Haven and the Daucleddau (see Figs. 1 and 3). The level of MHWS is shown by a broken line, and the non-tidal volume (below MLWS) is filled in with a dotted hatching. Note that the vertical scale is considerably exaggerated.

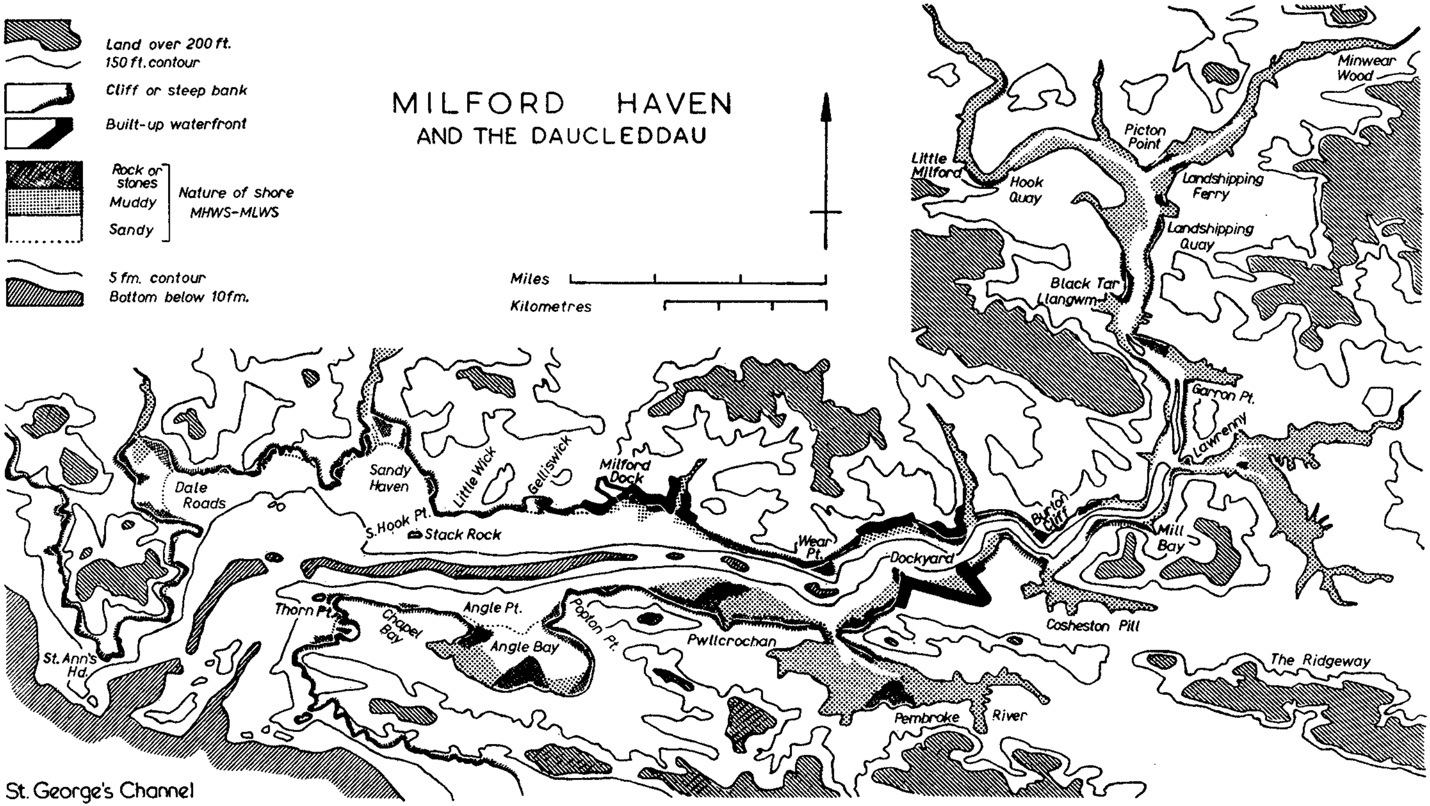

FIG. 3.
Milford Haven and the Daucleddau Estuary, showing the nature of the shores and surrounding ground.

Thorn Point). Gelliswick has a beach of small flat stones, and the entire area west and south of a line joining this bay and Thorn Point has a clean sandy or rocky bottom, and may be regarded as a sea-bay.

To the east as far as Milford Dock and Angle Point, the shores show the effect of greater shelter but bear no typically estuarine deposits. Angle Bay is extensive but shallow; the outer and eastern parts are of clean sand bordered by rock ridges and stone patches, but mud or muddy sand occurs in the inner portion. Although the channel is deep, this stretch of the Haven is wide; currents are slack compared with the upper reaches whilst wave action is much less than in the mouth. Conditions are thus suitable for the deposition of silt upon the bed, and material described as a soft, clayey mud covers bedrock to depths of up to 50 feet. The surface of bedrock is much fissured and shattered, so that flakes and chippings are abundant in the lower layers of this mud (Wimpey, 1957). Off Milford Dock there is also much clinker and other rubbish.

Between Milford Dock and Wear Point, the northern shore is of bedrock ridges, boulders and smaller stones at the foot of a low cliff above which the land rises steeply. The rocky lower shore gives way locally to banks of soft mud, and a large stable shingle spit dries out at low water off Wear Point. Neyland also has a stony beach, but there is much mud elsewhere along the northern shore of the Dockyard. The upper levels of the south shore from Popton Point to Pembroke Dock are rocky, but from about mid-tide level pass into the Pwllcrochan and Pennar Flats. These are fringed by firm muddy gravel at low water, and off Pwllcrochan there is a tongue of gravel and old shell supporting a well-stocked mussel bed; elsewhere, as within the Pembroke River, the mud may be very soft and mobile.

In the middle and upper reaches between Neyland and Llangwm, the channel is narrow and winding. The river cliffs are steep and powerful tidal scour keeps the deeper parts free of fine deposits, although gravel banks are built up on bends and silt is deposited wherever water movements are slack. A gravel bar, said to be of glacial origin, lies across the lower end of Castle Reach (see Figs. 8, 9); the channel deepens above this, but rapidly shallows north of Llangwm.

The most upstream shore which is rocky at all tidal levels lies below Landshipping Quay. There are ridges and reefs further north and, as at Landshipping Ferry, the ruins of quays provide stony substrata above mid-tide level. For the most part, the tidal stretches of the rivers Cleddau have low earth banks and a fringing strip of saltmarsh; the shore is often of firm muddy gravel at low water, but soft and mobile at intermediate levels. The bed is of firmer mud, with occasional gravel.

III. CLIMATE, WIND AND WAVES

Details of weather in the Western Approaches are given by the Meteorological Office (1940), and the climate of the Dale peninsula has been investigated by Oliver (1959). It may be summarized as mild and oceanic. Exceptionally severe weather was experienced in early 1963, and is discussed by Crisp (1964).

Fastnet Rock (the southernmost point of Ireland) bears 265° from St. Ann's Head, nearly due west; the Scilly Isles bear 200°, and Land's End is even more southerly. Thus between west and south, whence the prevailing winds and the strongest gales blow, the coast is open to the Atlantic Ocean. The fetch of waves from this quarter is theoretically several thousand miles, although in practice the greatest distance over which wind-raised waves travel continuously is said to be about 600 miles (see Williams, 1959). To the north-west and south-east respectively, Ireland and Cornwall are about 60 miles away. Using the formulae of Russell and Macmillan (1954), Williams calculated that waves reaching the Dale peninsula from between west and south might reach 15–20 feet, whilst from north-west or south-east their maximum height would be 10–12 feet. Waves from north-west through north to east cannot, of course, reach these shores. The force with which waves break on the shore is proportional to their height, and their action is reduced by a shallow or obstructed approach to the shore. The western extremity of Skomer Island, which has ten fathoms of water immediately offshore, is the most exposed in the vicinity of Dale. Headlands on the west of the peninsula are strongly wave-beaten, but because of the almost right-angled bend within its mouth, the Haven is protected from waves of great fetch approaching from directions other than the south-west. A line drawn through St. Ann's Head and Thorn Island intersects the northern coast of the Haven near Gelliswick, and to the east of this bay no direct effects are felt from south-westerly swell.

Reports of investigations made between December 1956 and November 1957 (Wimpey, 1957) commented upon the relationship between the force and direction of the wind, and the attenuation of wave-height between the mouth and the region Thorn Island–Milford Dock. The full force of the Atlantic swell, especially during gales, diminishes rapidly in the mouth; nonetheless, south to south-westerly winds of 20 m.p.h. or over produce a swell off Thorn Island which may be 10 feet high during the ebb, when the wind acts against the tide. This swell is undiminished at Stack Rock, but the highest waves recorded off Chapel Bay and Angle Point reach only 4 feet. Wave height in this region seems generally to be about half that in the mouth. During strong winds from the north-west or north, waves south-west of Thorn Island were only 3 feet high; a south-easterly gale raised waves of this height in Angle Bay. Easterly winds have a maximum fetch of about 8 miles at Dale, and westerly winds the same at Pembroke Dock. A south-easterly wind, blowing along the valley of the Pembroke River, can raise in Pennar Mouth a very choppy sea whose roughness is increased by a funnelling effect or the opposition of the tide; similar choppiness is also to be found in the upper reaches, but is very local because of the many bends in the channel.

Ballantine (1961) assessed the degree of exposure to wave action of shores around Dale; both he and Moyse and Nelson-Smith (1963) have attempted to express this factor in biological terms. Using their terminology, all the shores studied to the east of the limit of south-west swell are at least "sheltered". Many shores in the upper reaches are clearly very, if not extremely, sheltered, but environmental factors other than the degree of exposure make it impossible to apply to them this biological scale.

IV. Rainfall and river flow

Rainfall on the Dale peninsula is lower than inland or on the coast further to the east. The driest months on average are April–June, and the wettest

October–January. An appreciable gradient in rainfall is seen on passing inland up Milford Haven and the rivers Cleddau from St. Ann's Head with a 35-year annual average of about 36 inches to Maenclochog, near the source of the Eastern Cleddau, with about 63 inches; Narberth, near Canaston Bridge, has an average of 50·5 inches and Haverfordwest receives 46·4 inches. Table 1 gives details of rainfall at this latter station, which may be taken as typical of the region, set out for comparison with river flow data.

Table 1. *Monthly, annual and long-term average rainfall (inches) at Haverfordwest during the "water years"* 1960–61 *to* 1963–64. Data from the Monthly Weather Report for these years; average from Meteorological Office, 1958.

Month	*1960-61*	*1961-62*	*1962-63*	*1963-64*	*35 year average*
October	6·7	7·3	2·0	4·0	5·1
November	8·9	3·5	4·4	8·6	5·5
December	5·9	4·0	3·7	2·0	5·2
January	6·5	5·7	0·9	1·4	5·3
February	3·5	1·3	1·9	1·9	3·5
March	0·9	3·6	5·5	4·5	3·0
April	6·3	2·9	4·1	2·3	2·4
May	2·3	2·9	1·2	2·7	2·7
June	1·7	1·6	3·6	3·3	2·3
July	2·1	2·4	2·4	3·7	3·7
August	5·0	5·3	4·5	2·2	3·9
September	5·5	6·1	2·9	1·3	3·9
Total	55·3	46·6	37·1	37·9	46·4

Most of the fresh water entering Milford Haven is discharged by the Cleddau rivers. Flow data are recorded at Canaston Bridge (E. Cleddau) by the South West Wales River Board, and at Crowhill Weir near Haverfordwest (W. Cleddau) by the Pembrokeshire Water Board, or, previous to the end of 1962, the Prescelly Water Board. They have been corrected for present purposes to Picton Point, where the rivers join, on the assumption that flow at the more downriver station will be in proportion to the increased catchment area. The relevant catchment areas, as calculated by the River Board, are:

E. Cleddau above Canaston Bridge	70·7 sq. mi.	183 sq. km.
,, ,, Picton Point	89·6 ,, ,,	232 ,, ,,
W. Cleddau above Crowhill Weir	84 ,, ,,	218 ,, ,,
,, ,, Picton Point	120 ,, ,,	310 ,, ,,

The combined rivers Cleddau thus drain an area of over 200 square miles, or nearly 550 square kilometres (see Fig. 1).

The pattern of river flow closely follows that of rainfall. Detailed figures for recent years in Tables 2 and 3 show that the total volume discharged into Milford Haven during an average year by the rivers Cleddau is nearly 100,000 million gallons (over 450,000 million litres). Taken over the whole year, their combined mean daily flow at Picton Point is 260 million gallons; this combined

Table 2. *Total and mean daily flows in R. Eastern Cleddau (million gallons) corrected to Picton Point, for the "water years"* 1960–61 *to* 1963–64. Original data from South West Wales River Board.

Month	*1960-61*	*1961-62*	*1962-63*	*1963-64*	*Mean*
October	345·0	359·0	96·8	126·0	231·6
November	553·0	147·0	179·5	387·0	316·6
December	364·0	188·0	140·5	116·1	202·1
January	288·0	264·2	88·1	61·5	175·5
February	249·0	135·6	209·5	58·3	163·1
March	62·5	79·5	222·1	117·5	120·4
April	182·0	133·5	137·5	86·4	134·9
May	133·0	67·4	92·6	107·5	100·1
June	39·4	34·6	45·5	83·0	50·6
July	32·6	19·5	55·0	49·2	41·6
August	45·8	77·6	62·5	31·8	54·4
September	102·0	198·5	69·2	22·7	98·1
Total	76,556	52,014	42,574	37,915	52,265

Table 3. *Total and mean daily flows in R. Western Cleddau (million gallons) corrected to Picton Point, for the "water years"* 1960–61 *to* 1963–64. Original data extracted from the records of the Pembrokeshire Water Board. For considerable periods in November and December 1963, flows exceeded the upper limit of the recording gauge. Figures depending upon these records, or affected by the absence of records for 1960, are given in brackets. The total flow shown for 1960–61 has been estimated by comparison with the relevant records from the Eastern Cleddau.

Month	*1960-61*	*1961-62*	*1962-63*	*1963-64*	*Mean*
October	—	243·0	98·5	62·3	(134·5)
November	—	171·5	153·0	(330+)	(218·0)
December	—	200·0	153·5	(280+)	(211·0)
January	258·0	230·0	77·3	133·0	174·5
February	186·0	161·5	134·5	75·0	139·3
March	64·5	95·8	270·0	157·0	146·8
April	179·0	116·5	153·0	106·5	138·8
May	114·0	74·3	119·0	97·3	101·0
June	50·0	45·8	49·5	79·5	56·8
July	21·5	25·8	45·0	45·8	34·5
August	28·5	41·5	25·8	20·0	29·0
September	57·0	78·5	4·3	20·0	40·0
Total	(58,200)	45,193	39,595	(42,870)	(46,464)

flow is at its minimum of 76 million gallons per day in July, and reaches a maximum of 535 mgd. in November. The South West Wales River Board (1964) reports the lowest flows ever recorded as 4·83 mgd. (21·9 million litres per day) in the Eastern and 6·05 mgd. (27·5 mld.) in the Western Cleddau. Water for industrial users in the lower Haven is irregularly pumped from below Canaston Bridge, and domestic supplies are obtained from above Crowhill Weir. The prescribed minimum flows below these points are 8 mgd. in the Eastern and 5 mgd. in the Western Cleddau.

Another important single source of fresh water in the Daucleddau is the Cresswell River, which joins the smaller Carew River to form Lawrenny Creek. Its lowest flow was reported as 913,000 gallons per day in 1962 (South West Wales River Board, 1963). The combined volume discharged by the numerous pills in the upper reaches must be considerable, and minor streams drain across every shore. Moderate quantities of water flow into the lower Haven by way of the Pembroke River, Sandy Haven Pill and the River Gann, but cannot significantly alter the salinity of such a large volume of sea-water, constantly renewed by the tides. Williams (1959) studying the algae and Bassindale and Clark (1960) the fauna of the Gann Flat concluded that the effect of fresh-water flow on their distribution is overshadowed by that of other factors such as differences in the substratum.

V. TIDAL DATA

Spring tides in Milford Haven have a mean range of about 20 feet (6 metres) and an extreme range of more than 25 feet, or nearly 8 metres. Low water of spring tides occurs at approximately 0130 and 1330 hours GMT, and low water of neaps at about 0700 and 1900 hours. The occurrence of the lowest tides at about midday is very convenient for the shore collector, but it exposes to the most powerful insolation those lower-shore animals which may least be able to withstand it. Table 4 gives a variety of tidal data extracted from Admiralty sources. Levels are related to Chart Datum, which may be taken as ELWS and lies about 12 feet below Ordnance Datum (mean sea level at Newlyn). Mid-tide level is thus approximately 12 feet above Chart Datum.

During echo-sounding operations in Castle Reach and Beggar's Reach in March 1962, depths were recorded over a set course traversed every two hours for periods of 24 hours. When reduced to a common datum, these records enabled curves to be drawn for neap and spring tides which give a good indication of their pattern (Fig. 4). The range of neap tides in Castle Reach, just above Lawrenny, was about 1·4 feet greater than at Milford Haven; during springs the range was 3·3 feet greater. During spring tides in September 1964 the levels of several successive high tides at Lawrenny were compared with an Ordnance Survey benchmark there; they were 0·4–0·6 feet higher than those recorded by the tide gauge at Milford Haven. This conflicts with Admiralty figures for Lawrenny and Landshipping (Table 4a) dating from 1854 and indicating that the tide is diminished in the upper reaches. High water springs were observed 15 minutes later at Lawrenny than at Milford Haven.

In October 1964 tidal ranges were measured at Landshipping Ferry and at Minwear Wood (Fig. 3). At Landshipping, the range of neaps was 2·3 feet and of springs 3·8 feet greater than at Milford Haven (Fig. 5), while the level of high tide was at neaps 1·1 feet and at springs 1·5 feet higher than at Milford Haven. Minwear Wood is near the tidal limit in the Eastern Cleddau, and the river bed lies nearly at mean sea level so that the lower part of the tidal curve appears to be cut off. The range of neap tides is only slightly less than at Milford Haven, but the spring-tide range was nearly 9 feet less than in the lower reaches. Around low tide, the water level at Minwear may remain the same for five hours

Table 4. *Tidal levels and ranges in Milford Haven.*
ATT = Admiralty Tide Tables (Admiralty Hydrographic Dept., 1956–63),
AC = Admiralty Chart.

(*a*) *Mean Tidal Levels.*

(*ft. above Chart Datum*)	*MHWS*	*MHWN*	*MLWN*	*MLWS*	Range *springs* *ft.*	Range *springs* *m.*	Range *neaps* *ft.*	Range *neaps* *m.*	*Authority*
Skomer Island ..	21·6	16·7	8·1	2·4	19·2	5·85	8·6	2·62	ATT 1956, 1963
St. Ann's Head ..	21·6	16·5	7·3	1·9	19·7	6·01	9·2	2·80	AC 2879 (1952)
Milford Haven ..	23·0	17·2	8·1	2·2	20·8	6·34	9·1	2·77	ATT 1963; AC 3274 (1957)
Milford Haven ..	22·7	17·4	8·0	2·4	20·3	6·20	9·4	2·86	ATT 1956
Pembroke Dock ..	22·7	17·4	8·0	2·4	20·3	6·20	9·4	2·86	AC 3275 (1955)
Lawrenny	19·9	14·5	—	—	—	—	—	—	AC 2877 (1854)
Landshipping ..	19·9	14·5	—	—	—	—	—	—	ATT 1956, 1963; AC 2877 (1854)

(*b*) *Extreme Tidal Levels*
(*ft. a.c.d., predicted for Milford Haven, ATT* 1957-63)

	extreme	*mean*
Highest high water	26·0	25·6
Lowest high water	15·7	16·0
Highest low water	9·3	9·0
Lowest low water	− 0·3	0·0

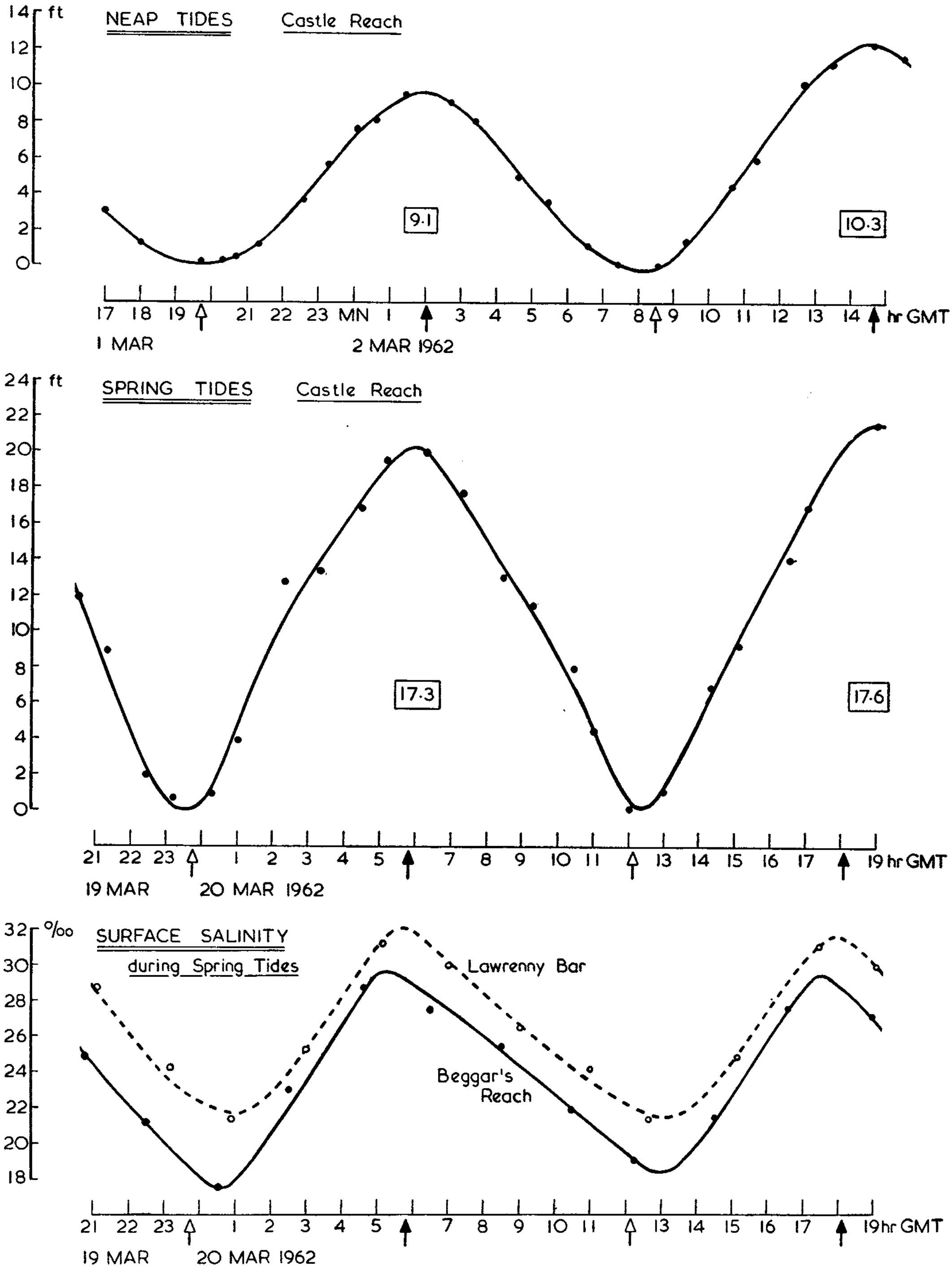

FIG. 4. Observations of the range of neap and spring tides above Lawrenny, made by echo-sounding. The range (ft.) of each tide at Milford Haven is shown in a box. The time of low water at Milford Haven is indicated by an open arrowhead, and of high water by a solid one. Surface salinity changes are shown below; it appears that in the surface waters, the ebb persists for longer than the flood.

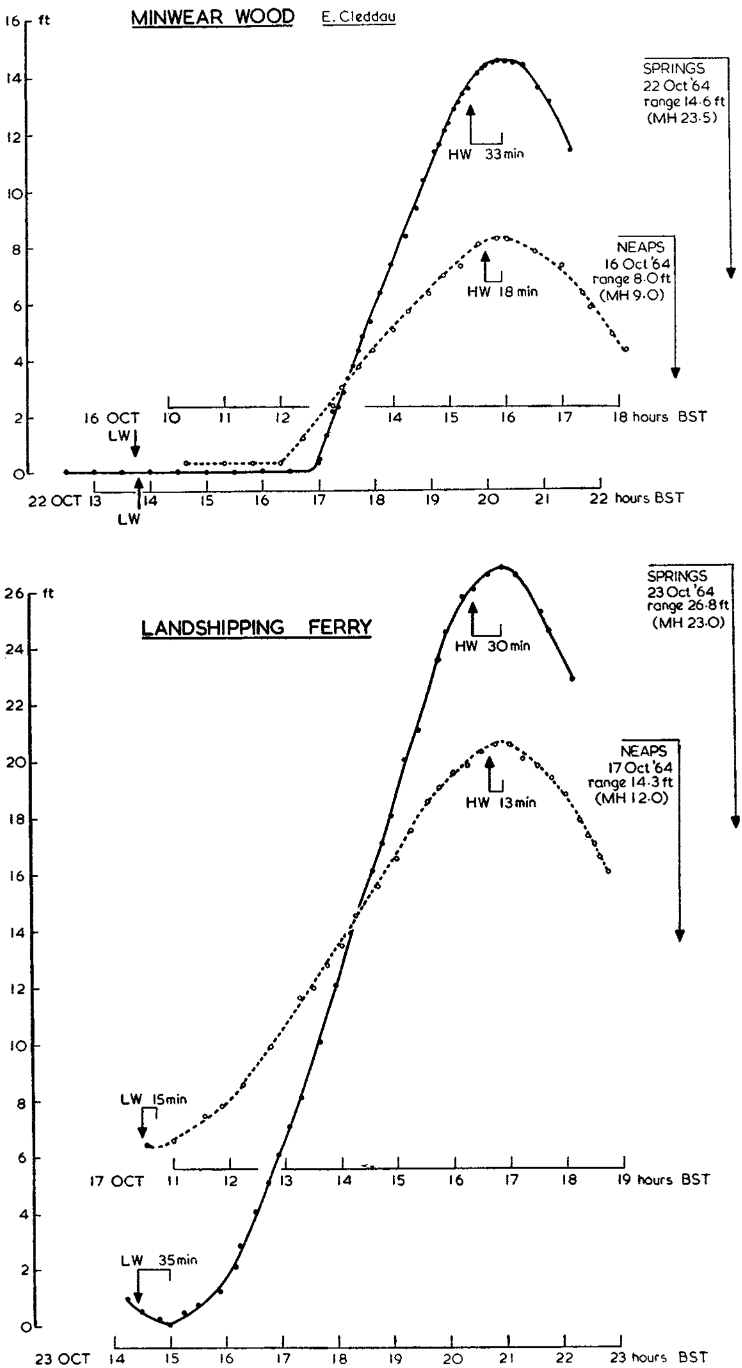

FIG. 5. Observations of the range of neap and spring tides at two stations in the Eastern Cleddau River. The curves are superimposed so that times of high tide coincide. Arrows indicate the times of high and low water at Milford Haven; the length of delay is written beside them. The range of the same tide at Milford Haven is also shown.

or more. At Landshipping the turn of the tide was delayed by 13–15 minutes at neaps, and 30–35 minutes at springs; high water at Minwear appears to occur only a few minutes later than at Landshipping.

Admiralty Tide Tables report that high water of both springs and neaps occurs 21 minutes later at Landshipping and 36 minutes later at Haverfordwest than predicted for Milford Haven. Simultaneous gaugings made by the local authorities at Neyland and Haverfordwest in 1956 also showed a mean delay of 36 minutes between Milford Haven and Haverfordwest both at high and low water, and a small delay between high water at Milford Haven and Neyland. Tidal ranges diminish rapidly above Little Milford on the Western Cleddau, and at Haverfordwest they are given by the Admiralty Hydrographic Department (personal communication, 1964) as 7·2 feet at springs and 2·5 feet at neaps. The 1956 gaugings agree with this at the time of an ordinary spring tide, and show a range of 8·75 feet during a good spring. The level of high water at such an upriver station will partly depend on the amount of fresh water flowing down, but it appears to be consistently rather higher at Haverfordwest than at Milford Haven. The highest and lowest values recorded for each year between 1955 and 1958 were compared with Tide Table predictions for the same dates at Milford Haven and showed an average increase of 1·75 feet and 1·25 feet respectively.

Tidal influences are not felt above Crowhill Weir, north of Haverfordwest on the West Cleddau, nor above Blackpool, south of Canaston Bridge on the East Cleddau. For some distance below these points tidal changes in salinity are very small even at spring tides, i.e. the tide is largely a fresh-water one. The only tidal information available on other tributaries feeding Milford Haven is a note in the West Coast Pilot (Admiralty Hydrographic Department, 1948) that the range of spring tides at Cresswell Quay is 12 feet. According to Ordnance Survey maps, the tide ceases to have effect only a short distance further up the Cresswell River.

VI. WATER MOVEMENTS

Because of the relatively large tidal range, movements of water masses within the Haven are extensive. Its full volume (to EHWS) between Thorn Island and Picton Point was calculated from sections of the channel to be 76,000 million gallons or 345,000 million litres; the empty volume (to ELWS) is only 34,000 million gallons (154,000 million litres) so that the tidal volume at springs is over 40,000 million gallons or nearly 200,000 million litres. In July 1958, a drogue and float were followed after release in the upper Daucleddau (P. J. Warren, unpublished data, 1958). On the ebb of a spring tide they travelled from Picton Point to the eastern end of the Pwllcrochan Flats, a distance of 9·5 miles (15·3 kilometres), while a neap-tide ebb carried them 5·7 miles (9·2 kilometres) from Beggar's Reach to Pembroke Dockyard. Drogues were also released on the ebb tide from Pennar Gut in the course of site investigations for the Pembroke Power Station (C.E.G.B., personal communication, 1964). At spring tides a number of them escaped from the Haven, although neap ebbs did not carry them as far as the mouth. However, surface isohalines at high and low water (Fig. 11) indicate smaller movements than these.

Table 5 gives details of current speeds in the lower Haven; off Neyland and

Burton Cliff differences between flood and ebb velocities are due to local eddies and cross-currents. The speed of neap-tide currents is about half that of springs. Velocities measured in February 1959 on spring tides throughout the lower and middle reaches (Posford, Pavry and Partners, 1959) were generally rather lower than these Admiralty values. The Hydraulics Research Station team (1958) recorded a maximum of 94·5 cm./sec. at the surface off Burton Cliff during the ebb of an intermediate tide in July 1957. A maximum flood velocity of 110 cm./sec. was recorded for Castle Reach on a poor spring tide in November 1961, and of 140 cm./sec. over Lawrenny Bar during good springs in September 1964.

Table 5. *Velocity of tidal streams in Milford Haven* from data given on Admiralty Charts 3274 (1957) and 3275 (1955).

Position (mid-channel)	*State of tide*	*Velocity (cm./sec.)* *springs* *mean*	*max.*	*neaps* *mean*	*max.*
In mouth	Flood	36·0	56·7	15·5	26·7
	Ebb	36·0	56·7	15·5	26·7
Off Chapel Bay	Flood	46·5	87·5	20·5	41·2
	Ebb	46·5	87·5	20·5	41·2
Off Wear Point	Flood	62·0	92·7	31·0	41·2
	Ebb	67·0	98·0	31·0	46·4
Off Neyland Point	Flood	72·0	118·5	36·0	61·8
	Ebb	26·0	61·8	10·5	30·9
Off Burton Cliff	Flood	31·0	67·0	15·5	30·9
	Ebb	87·5	128·0	41·0	61·8
Mouth of Pembroke River ..	Flood	51·5	87·5	20·5	41·2
	Ebb	56·5	98·0	26·0	46·4

During the Hydraulics Research Station investigation, current velocities were measured off Burton Cliff at the surface, in mid-water and on the bottom. It was found that high slack water occurred almost simultaneously at all depths some 20 minutes later than the prediction for high water at Milford Haven, but the tide began to flood nearly 45 minutes earlier on the bottom than in mid-water or at the surface, and about 15 minutes earlier than the predicted time of low water at Milford. Differences of water movement with depth were investigated further in 1961, using jelly-air bottles (Carruthers, 1958). Tethered at intervals to a weighted line, these are partly filled with a free-flowing warm gelatin solution. When lowered to the required depth, the bottle inclines to the current and the solution sets. The speed of the current is determined from the angle of the jelly surface, and its direction from a compass which floats in the jelly. Observations were made below Mill Bay (Fig. 6) and in Castle Reach (Fig. 7). At both stations a difference of nearly an hour divided slack water in the upper and lower levels, not only at low tide as off Burton Cliff but also at high water. These differences increased the duration of flood and reduced the duration of ebb at lower levels, and had the reverse effect at upper levels. During the echo-sounding survey of 19–20 March 1962 surface salinity samples were taken in Castle Reach and Beggar's Reach at the most upstream and

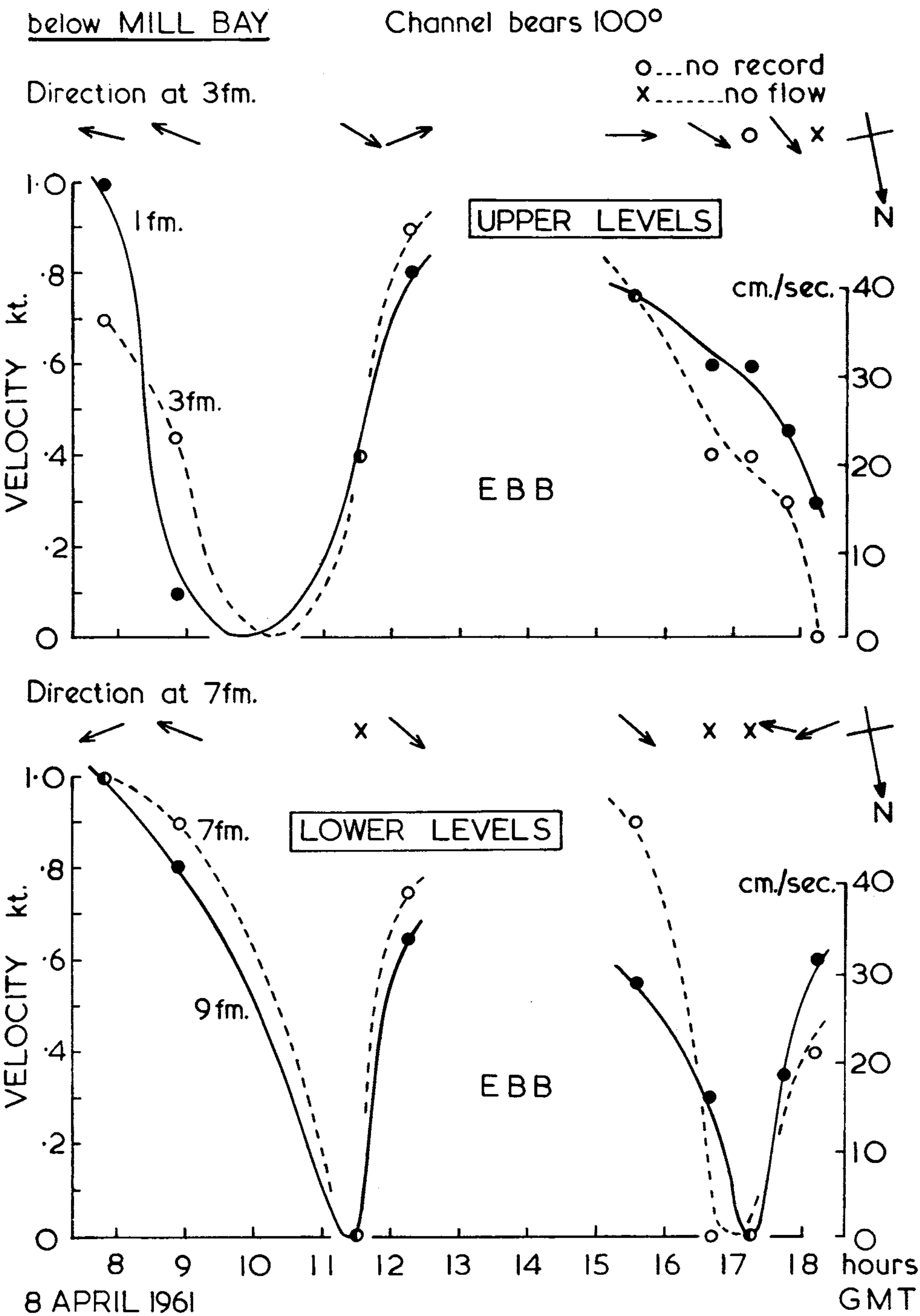

Fig. 6.

Observations of current speed and direction, made with jelly-air bottles during a neap-tide ebb below Lawrenny. It appears that surface waters begin ebbing before those at lower levels and continue ebbing for longer.

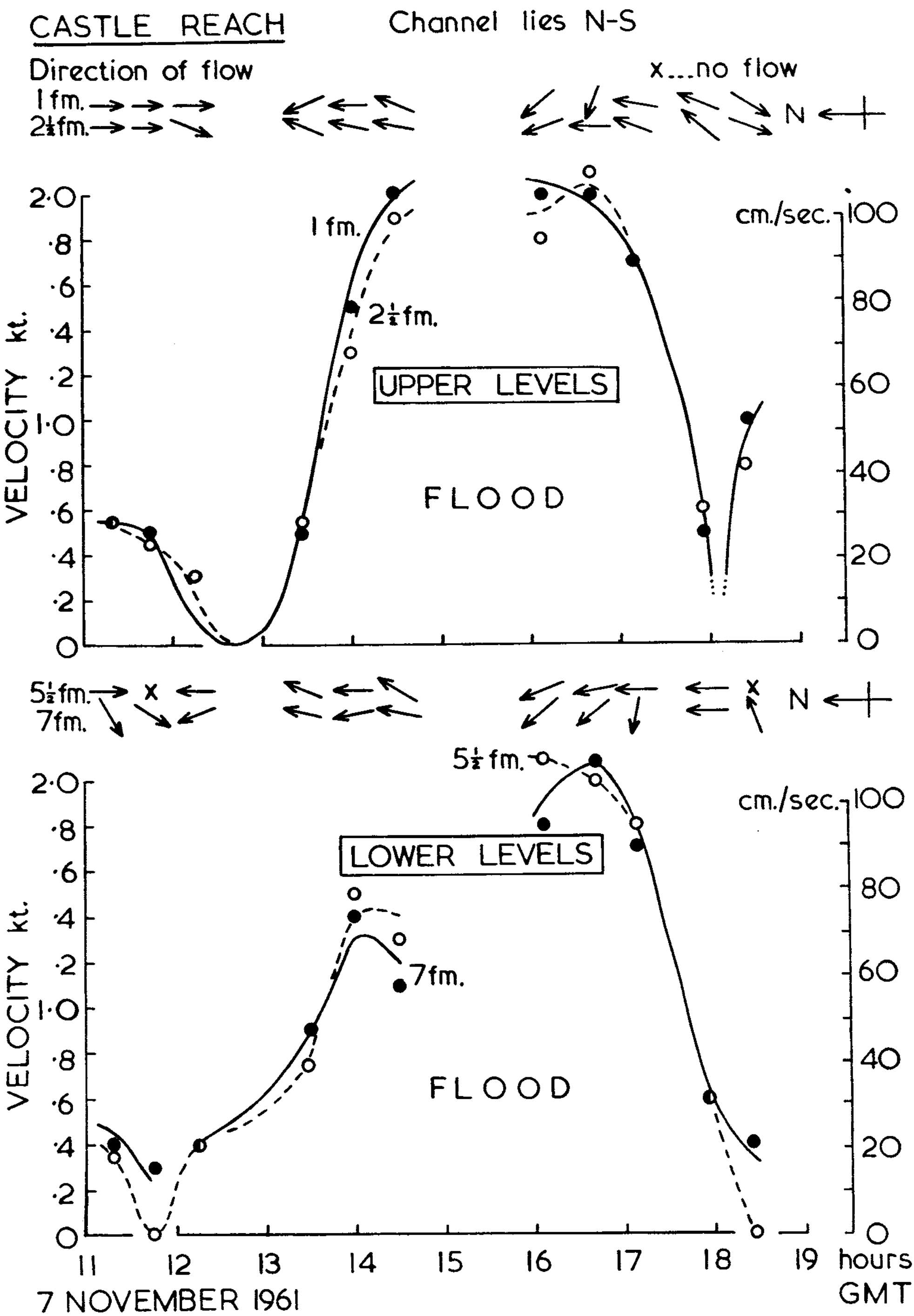

Fig. 7.

Observations of current speed and direction, made with jelly-air bottles during a spring-tide flood above Lawrenny. The flood tide begins earlier and lasts longer at lower levels than in surface waters.

downstream positions traversed (Fig. 4). The lowest salinities were recorded about one hour after low water, although maxima were reached at the same time as, or even before, high water. If it is assumed that the points of inflexion on these salinity curves correspond with slack water at the surface, it is again seen that the surface waters ebb for about an hour longer than they flood. As the tidal depth curve also shown for this period is symmetrical about high and low water, the ebb at lower water levels must run for a shorter time than the flood in order to compensate for the observed surface movements.

If these differential movements take place with every reversal of the tide, there must be a net flow of bottom water up the estuary, opposed by a net motion of surface water towards the mouth. Such a circulation has been described, for example, in Chesapeake Bay by Pritchard (1952a, 1952b, 1955). He pointed out that this could account for the upstream transport of oyster larvae in the James River there, and quoted (1952b) a similar explanation by Bousfield of the distribution of barnacle larvae in the Miramichi Estuary. Dr. H. A. Cole, in a mimeographed report of 1956, referred to a then unexplained mechanism which tends to hold oyster larvae in the upper reaches of Milford Haven, and Dias, in her 1960 thesis on the plankton of this estuary, demonstrated a distribution of young herring larvae which can now be reconciled with the position of the known herring spawning-ground.

VII. STRATIFICATION

Water joining the suggested circulation pattern from the seaward end of the estuary and forming a "salt wedge" on the bottom will be at a higher salinity than that moving down on the surface. This surface water, contributed partly by the rivers, will tend to be colder than bottom water in winter and warmer in summer. Vertical stratification is therefore to be expected. Observations of the Hydraulics Research Station (1958) include salinity records of 16 ‰ on the surface and 23 ‰ on the bottom in the Western Cleddau at Black Hill (above Little Milford) during high water of an ordinary tide. More recently, salinities of 1·7 ‰ at the surface and 24·2 ‰ on the bottom were recorded during high water of neap tides in the Eastern Cleddau at Minwear Wood; such differences were less extreme during spring tides, or lower down the river at Landshipping Ferry (Figs. 12 and 13).

A more detailed picture of stratification in the upper reaches was obtained by sampling, at low slack water, sections extending from Lawrenny to Landshipping (Fig. 8) or over Lawrenny Bar (Fig. 9). Salinity differences of about 8 ‰ were observed between surface and bottom waters both off Black Tar, Llangwm and below the Bar. Further downstream, readings made below Mill Bay in April 1961 showed a vertical difference of nearly 3 ‰, and in mid-channel below Pembroke Dockyard in May 1962 differences of about 2 ‰ were observed at low water springs. However, it is to be expected that vertical mixing will be almost complete in the wider, deeper channel seaward off Wear Point at all stages of the tide.

VIII. SURFACE SALINITY

The salinity of coastal waters off south-west Pembrokeshire was shown by Lee (1960) to lie between 34·0 and 34·4 ‰. Within Milford Haven, the

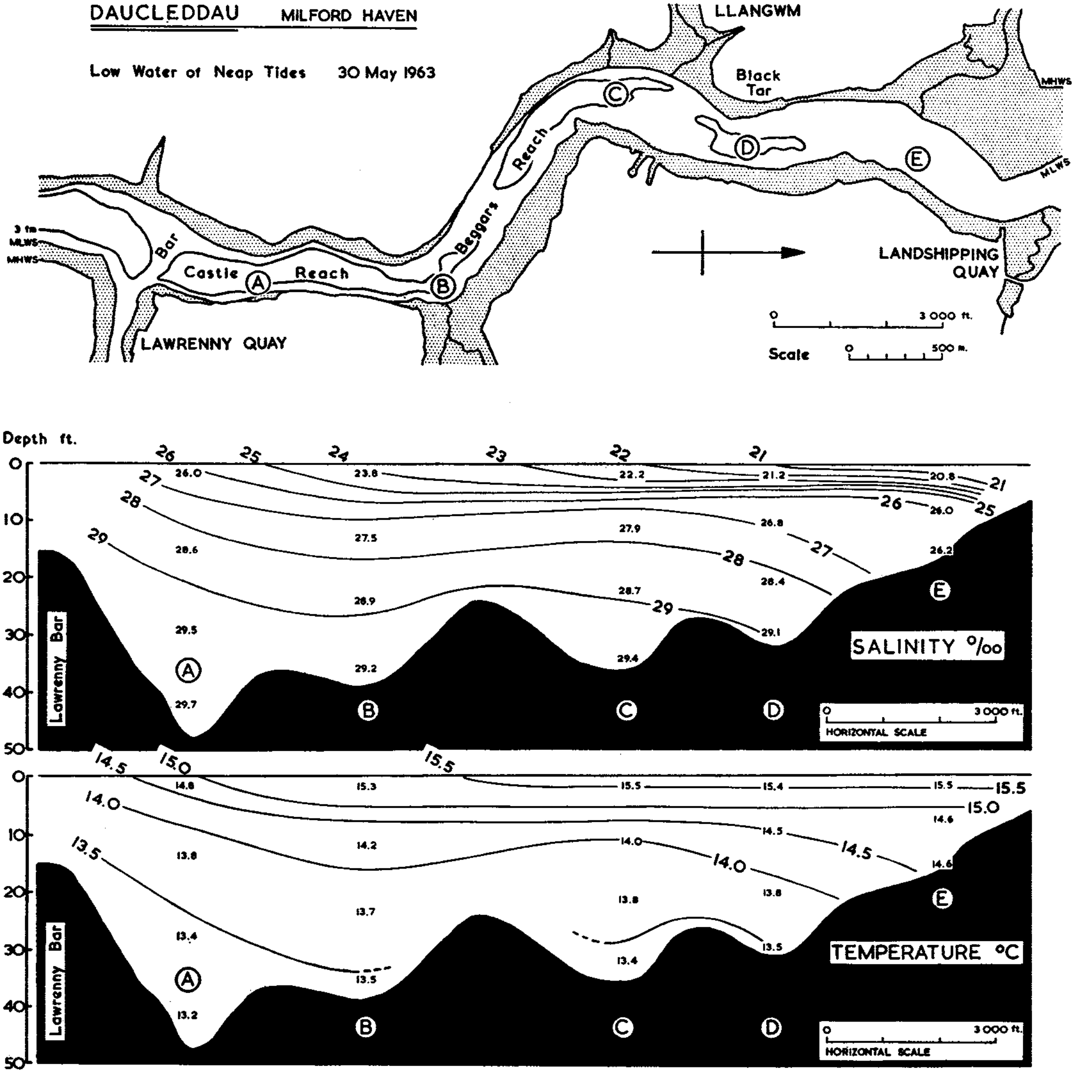

Fig. 8.

Stratification along a three-mile section of the Daucleddau, showing isohalines and isotherms at low slack water of neap tides.

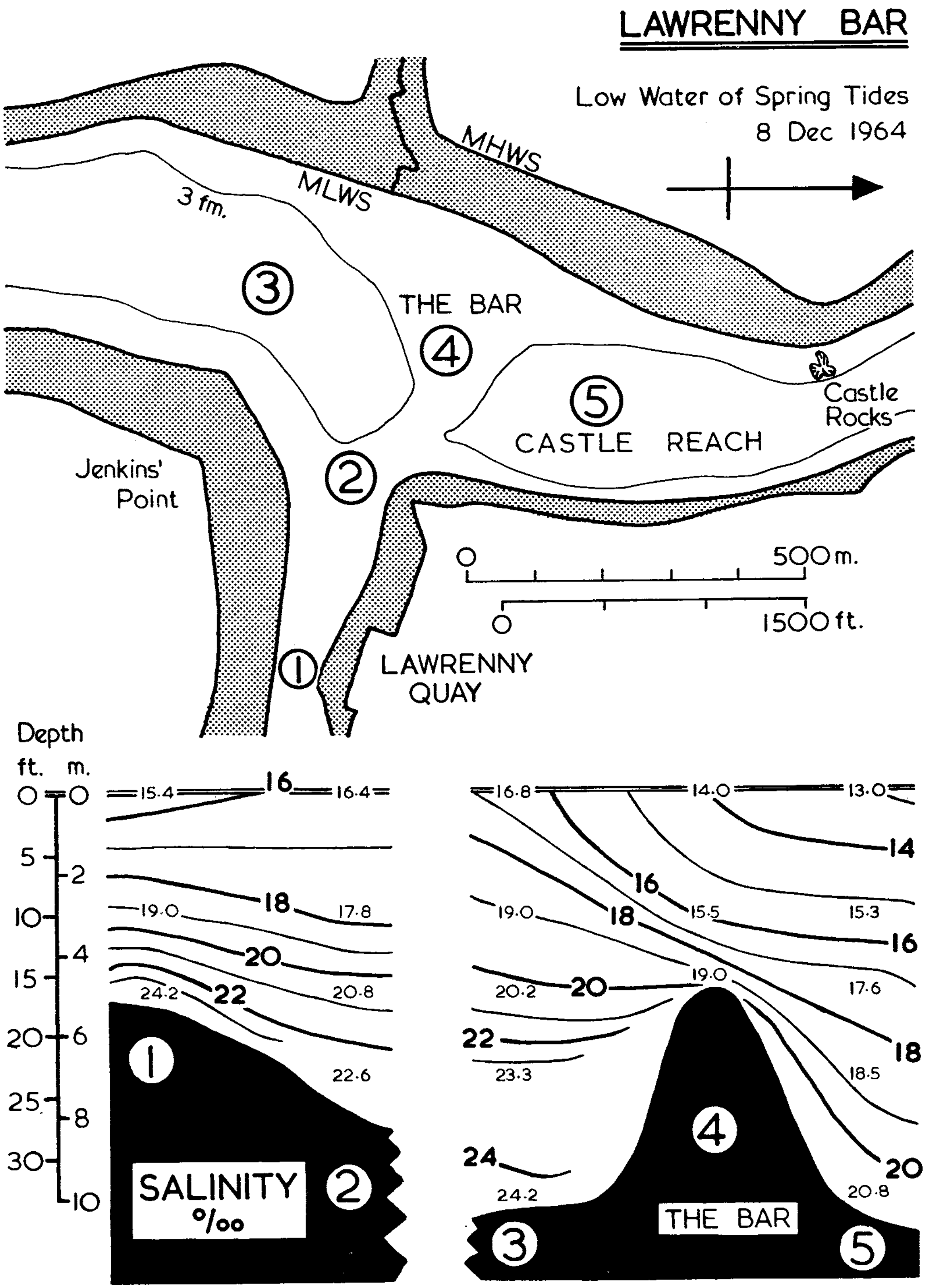

FIG. 9.

Stratification over Lawrenny Bar and in the mouth of Lawrenny Creek, showing isohalines at low slack water of spring tides. The temperature throughout was around 9° C.

Hydraulics Research Station reported (1958) observations during an ordinary tide in July 1957, when the rivers were filling after heavy rain; D. C. Arnold (unpublished report, 1959) sampled the surface waters at spring and neap tides in February 1959. Curves drawn from these records are shown in Fig. 10, and Arnold's data are also shown as isohalines in Fig. 11.

Because of the large volume of the Haven and the small amount of fresh-water inflow relative to tidal incursions, salinities remain high for a considerable

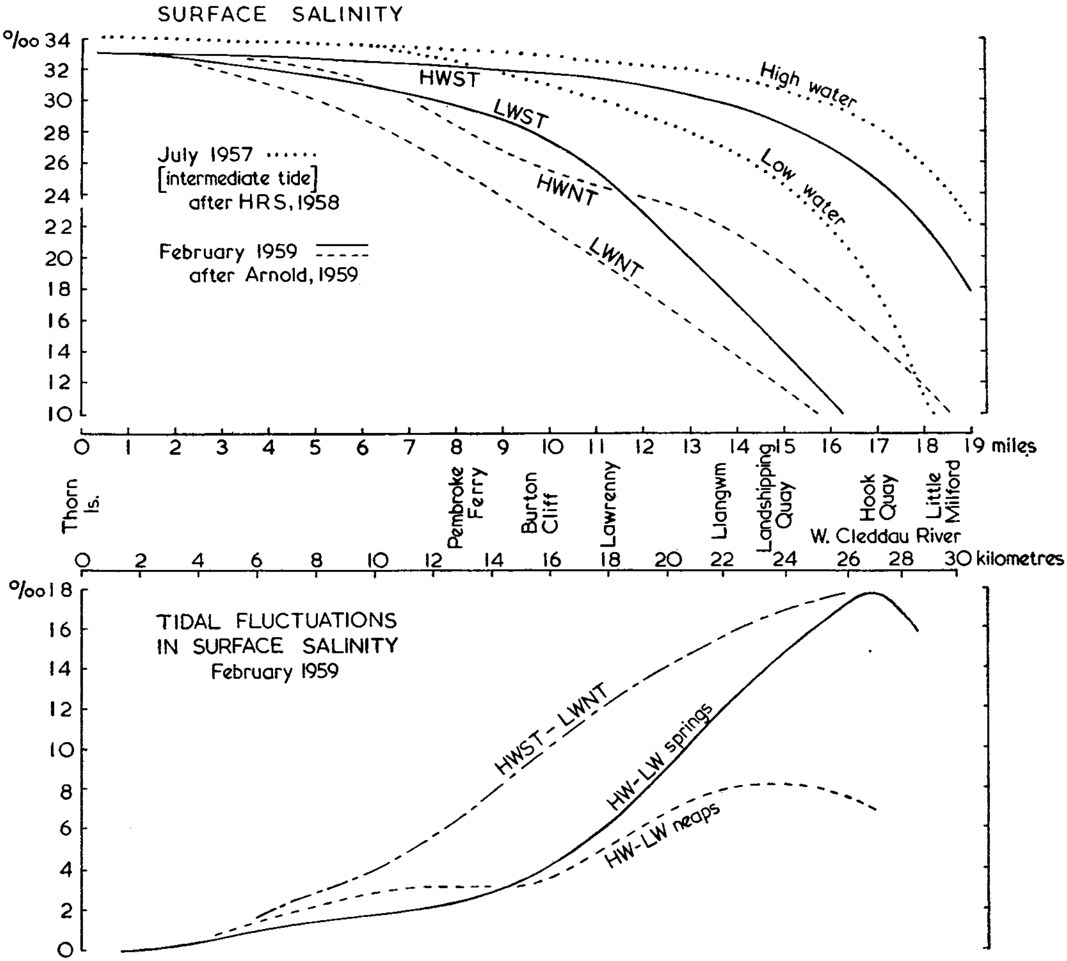

FIG. 10.

Curves showing surface salinity gradients in Milford Haven, from Thorn Island to the lower reaches of the Western Cleddau River. The greatest fluctuations in surface salinity occur around the head of the Daucleddau.

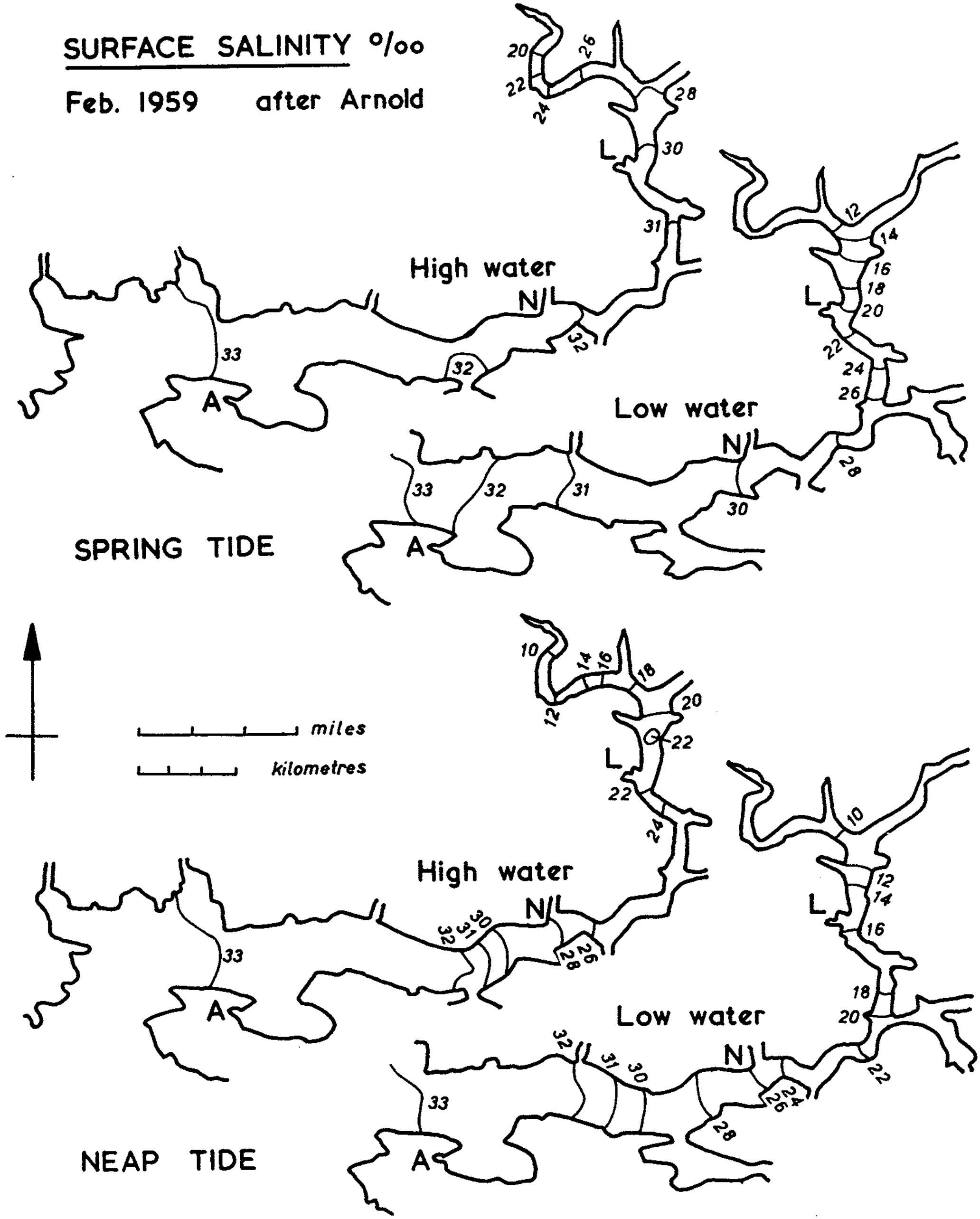

FIG. 11.

Surface isohalines in Milford Haven and the Daucleddau, drawn from Arnold's unpublished data of 1959. A = Angle, N = Neyland, L = Llangwm.

distance up the estuary. To the seaward of Wear Point they probably never fall below 30 ‰. The Hydraulic Research Station reported 34·5 ‰ at the surface off Chapel Bay, and records of 34·6 ‰ at depth and 34·1 ‰ on the surface have been obtained below Pembroke Dockyard. Surface waters reach 32–33 ‰ in Lawrenny Creek and Castle Reach at high tide during prolonged dry weather, but in the reaches above Lawrenny Bar the water normally becomes increasingly fresh, and tidal fluctuations in salinity reach their maxima (see the lower curve in Fig. 10). In October 1964, during wet weather but while the rivers were still fairly low, changes in the salinity at low-water mark were compared with those at the surface of the flooding tide at Minwear Wood, near the tidal limit in the Eastern Cleddau (Fig. 12) and at Landshipping Ferry (Fig. 13). Surface salinity during springs at Minwear abruptly rose to around 18 ‰ for just over an hour about the time of high tide, but at neaps it barely rose above zero. At low-water mark the penetration of saline water was more marked and readings rose above 20 ‰ for a number of hours. Not far upstream of this station the tide is probably almost entirely a freshwater one. At Landshipping there was much less difference between salinities at the two levels and, apart from irregularities due to local eddies, they rose steadily throughout the flood, extending through a wider range (ca. 6–30 ‰) during the spring tide.

IX. Water temperature

The annual variation in mean and extreme surface-water temperatures between July 1955 and August 1962 in Dale Roads is shown in Fig. 14. There are no similar records available from elsewhere in Milford Haven or the Daucleddau. Many observed or reported random readings suggest that the Dale curve gives a general indication of mean conditions throughout the estuary, although greater extremes and more rapid changes might be expected in the upper reaches. P. J. Warren (mimeographed report, 1958) recorded in Lawrenny Creek maxima of 19·5° C. in July and 18·9° C. in September, at the upper limit of the Dale range for these months; a minimum of 10° C. in July is below the lowest Dale record. The months of January and February, during which sea temperatures are lowest in any year, were abnormally cold in 1963. Sea-ice formed around the Gann Flat, Dale and on shores in the upper reaches this was augmented by frozen snow-slush and ice-floes carried down by the rivers. Details of this winter and its biological effects are given by Crisp (1964) and Moyse and Nelson-Smith (1964). During any severe winter, the stresses imposed on their flora and fauna by the normal estuarine gradients are intensified by unusually low temperatures in the upper reaches. In Milford Haven particularly, this may be an important factor in determining the penetration of those southern species which are approaching their northward limits along this part of the Welsh coast. Interesting changes in the balance between competing Arctic and southern forms may be expected if the cooling-water effluent from the Pembroke Power Station should increase even to a small extent the mean water-temperature in the Haven (see, e.g. Naylor, 1965).

X. Turbidity and pollution

Turbidity is a very variable and transitory property, depending a great deal on weather and tide, and the values given here serve mainly to indicate that the

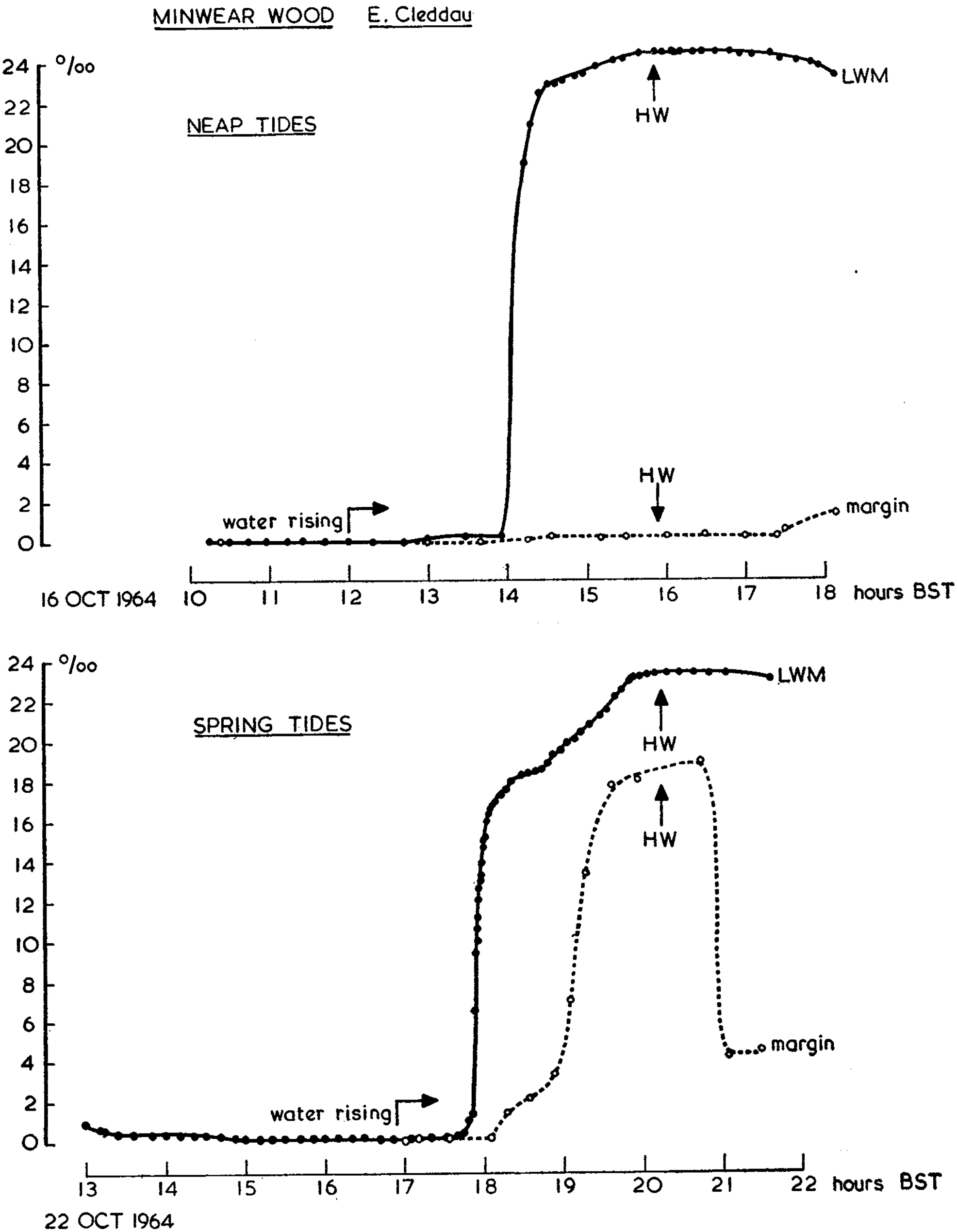

FIG. 12.

Salinities at Minwear Wood on the Eastern Cleddau River during the flood of neap and spring tides. Readings were taken just below low-water mark (solid line) and at the surface near the water's margin (broken line). The sampling points thus coincided at low water, but at high water were separated by the amount of the tidal range. The flood is at first a fresh-water one, and the intrusion of saline water is detected earlier along the bottom than at the surface. Tidal observations made on the same dates are summarized in Fig. 5.

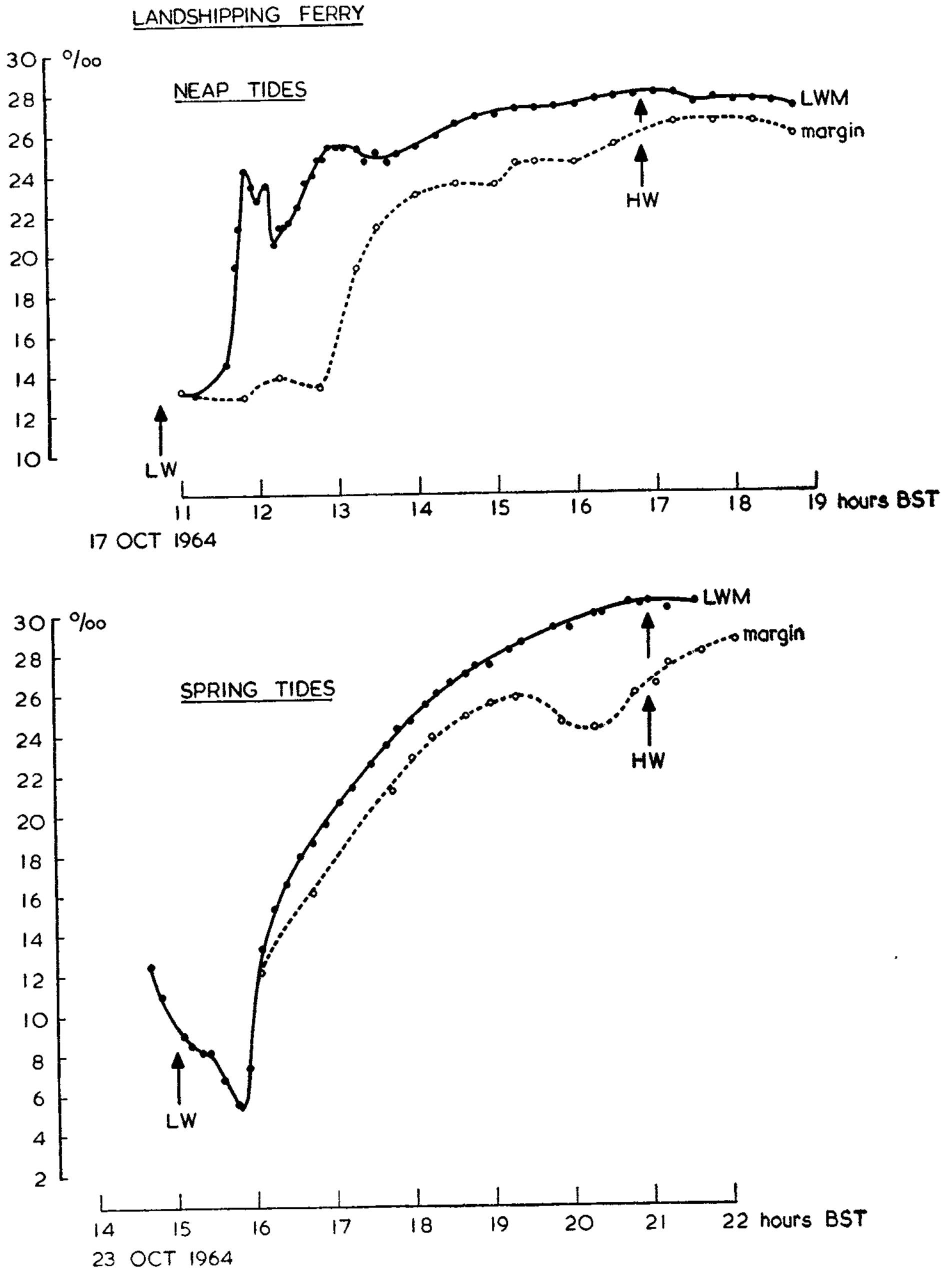

FIG. 13.

Salinities at Landshipping Ferry during the flood of neap and spring tides, taken as at Minwear Wood (see Fig. 12). During neaps, flooding water of higher salinity was detected more than an hour earlier along the bottom than at the surface. Tidal observations made on the same dates are summarized in Fig. 5.

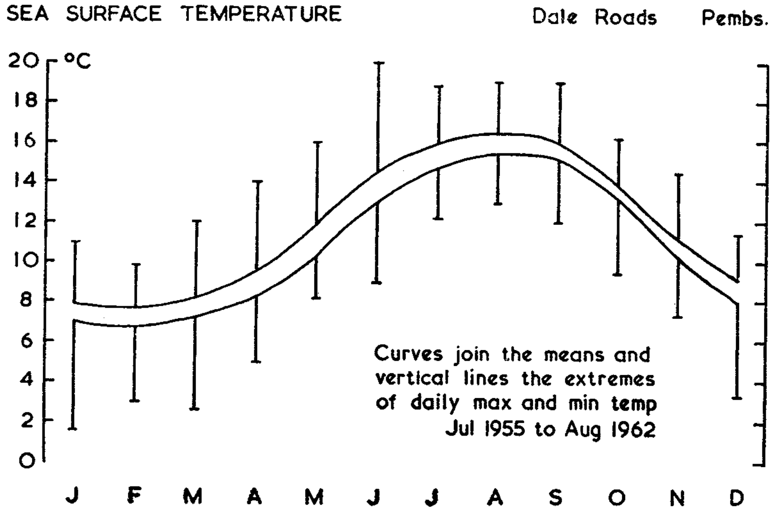

FIG. 14.
Sea-surface temperatures in shallow water off Dale, recorded by a thermograph mounted on a moored raft maintained by Dale Fort Field Centre.

waters of Milford Haven and the Daucleddau are not as heavily turbid as those of other, less rocky estuaries. The Hydraulics Research Station (1958) investigated the concentration of suspended solids at various depths throughout Milford Haven and found a range of 10–55 ppm., with a mean of 23·5 ppm.; the highest concentration was from near Hook Quay, and the value for the Western Cleddau River at Haverfordwest was 24 ppm. Posford, Pavry and Partners (1959), operating in February 1959 during a poor spring tide, reported the rivers at Haverfordwest and Canaston Bridge to be very clear, carrying only 5 ppm. of solids. They estimated that this was the turbidity off the open coast. However, they referred to a value of 70 ppm. obtained by Messrs. George Wimpey at Canaston Bridge. Within the Haven itself they reported a mean of 23·5 ppm. within a range of 4–60 ppm., a confirmation of the H.R.S. figures. An exceptional value of 893 ppm. was recorded from near the bottom at Hook Quay on a strong ebb tide.

In the River Thames values of more than 1,000 ppm. are normal for samples of bottom water, and the concentration in winter may exceed 50,000 ppm. (H.R.S., 1958). Bassindale (1943a) reported concentrations of up to 6,000 ppm. suspended material in the middle reaches of the Severn Estuary, although in the mouth or the upper, non-tidal reaches of the river readings may be less than 50 ppm.

P. J. Warren (unpublished data, 1958) used a Secchi disc in Lawrenny Creek to record visibilities of 1–5 metres, and in early March 1962 the visibility in Beggar's Reach, below Llangwm, was found to lie between 1·2 and 1·8 metres. Some much more subjective observations, made during the course of many boat-trips up and down the estuary, suggest that the greatest turbidity is usually encountered in the water mass which lies, according to the state of tide, in one of the reaches between Pembroke Dockyard and Llangwm. At low water, the lower tidal reaches of the rivers may also seem particularly muddy.

The South West Wales River Board (1962) published analyses of samples from the W. Cleddau River which are summarized in Table 6. All values except those from Hook Quay are the means of three determinations, using standard methods. At Lawrenny in summer the pH is 8·2–8·3 (Warren, unpublished data, 1958) which is typical of the open sea. It is clear that in the lower tidal reaches, the concentration of dissolved oxygen is also high at all depths.

Table 6. *Analysis of Samples from the Western Cleddau River.*

Station	*pH*	*B.O.D.* (*ppm.*)	*Ammoniacal nitrogen* (*ppm.*)	*Dissolved oxygen* (*% satn.*)
Crowhill Weir	7·55	2·05	0·26	100·33
Merlin's Brook, confluence below Haverfordwest	6·95	8·05	4·56	87·78
Little Milford	6·90	1·75	0·09	83·84
Hook Quay (single sample)	7·00	1·60	0·02	76·65

A fairly large volume of untreated sewage is discharged into the W. Cleddau River at Haverfordwest, and Merlin's Brook carries into it a high concentration of dairy-processing wastes. Small quantities of domestic sewage are discharged throughout the Haven, but rapidly become diluted and carried away. Such effluents are on balance biologically favourable, and determinations of the degree of shellfish pollution by faecal *B. coli* (Cole, 1953; mimeo. report, 1955) have always given results well within limits acceptable for human consumption. At present the Haven may be described as unpolluted except for occasional spillages of crude oil.

The literature dealing with the toxicity or other harmful effects of hydrocarbon oils in aquatic environments has been fully reviewed by McKee (1956); Galtsoff (1936), Hawkes (1961) and Zobell (1964) concerned themselves with oil pollution of the sea only. Most workers agree that crude or fuel oils, at the concentrations in which they are likely to occur in the open sea, rarely cause immediate damage to any but the most sensitive organisms, although continual pollution at quite a low level has been blamed by some for the impoverishment of the flora and fauna of ports or docks. Floating oil causes much damage to sea birds, and is thus particularly unwelcome in the vicinity of the offshore bird islands. Sunken or stranded oil can be a serious local danger when it is present in large quantities, or at the top of the shore where it may not be washed off by the next tide, but its main toxic constituents are either readily water-soluble or evaporate rapidly, so that it usually becomes chemically harmless after quite short periods of normal weathering. Although it is obviously desirable to disperse floating oil and to remove stranded oil from foreshores which are much used, most methods of cleansing, especially the use of chemical emulsifiers, are more harmful to shore life than the original pollution (see, e.g. George, 1961).

XI. THE DISTRIBUTION OF MARINE SPECIES

Fischer-Piette (1931) showed that salinity is the most powerful factor limiting the penetration of marine animals and plants into estuaries, and this is apparently true for Milford Haven. The difficulty is to decide the relative importance to any one species of such variables as the lowest value attained, the time for which salinities below a certain critical level must be endured, or the range experienced during a given period or a particular stage in the life-cycle. Other important factors which have been dealt with here, such as siltation, turbidity, scouring by strong currents or unusual temperatures, also vary in intensity in different parts of the estuary. Some animals, otherwise capable of extending further upstream, are limited by a scarcity of suitable substrata; others by the distribution of their prey or food-plant. Many which merely enter the mouth of the Haven appear to require vigorous wave-action or clean oceanic water. On the other hand, some species more typical of rocky sea-shores than estuaries penetrate far into the shelter of the lower reaches and are absent from many of the more exposed shores around the mouth. Most of the forms indicative of sheltered sea-shores do not pass upstream beyond Landshipping, although the lower reaches of the rivers contain a number of organisms equally common on the open coast. Freshwater species were not included in this study, for although upon passing up an estuary the marine component diminishes gradually, the freshwater component does not replace it in stages but appears almost complete at the head.

The environmental influences responsible for changes in vertical zonation are also varied. Among the forms typical of exposed shores, a marked narrowing of the vertical range in the barnacle *Chthamalus* and the alga *Corallina* on passing into the Haven simply reflects the increase in shelter from wave action (see, e.g. Moyse and Nelson-Smith, 1963); neither penetrates far enough into the Haven to be affected by truly estuarine influences. A similar lowering of the entire zone of supralittoral lichens, and of the upper limit of small winkles, must also be a consequence of greater shelter. In the upper reaches, vertical stratification exaggerates tidal changes in salinity over the lower shore, so that the animals and plants living there have to contend with a greater range as well as with lower values of salinity. In many tidal estuaries, where only a small volume remains at low tide in the channels between extensive mud-flats, horizontal movements of the water are greater during the last part of the ebb and the first of the flood than when the flats at higher levels are flooding or draining; the rate of change in salinity is then also greatest on the lower shore. In deep rocky estuaries like Milford Haven this is significant only in the most upstream reaches. In the sublittoral zone, the range of salinities experienced at any given station during one tidal cycle is less, and their values may always be higher, than in the intertidal region. Salinity variations of this sort have previously been demonstrated in the Tamar by Milne (1938) and some of their possible effects have been discussed by Spooner and Moore (1940) and Moore (1958). Certain marine species, finding conditions unfavourable on the lower shore, may either occupy higher levels as does the barnacle *Balanus balanoides* in the Daucleddau, or pass into the sublittoral at their more upstream stations like the sting-winkle *Ocenebra*.

Where vertical stratification persists during the flood, it is also true that salinities at high tide are greater on the lower shore than around high-water mark. Animals unable to extend their vertical range upwards may still penetrate far into the estuary if they can tolerate the necessity of closing up or retracting into shelter at times of low tide, like the topshell *Gibbula umbilicalis* or the sea-anemone *Actinia equina*. Those capable of protecting themselves in some manner from conditions which are temporarily unfavourable, as can limpets and winkles, may occupy the same levels throughout an extensive range.

It is intended to discuss further the factors which influence distribution patterns of individual species in a later publication describing these patterns.

XII. Ecological zones in estuaries

Marine plants and animals may thus show gradual changes in their vertical zonation, or reach the limits of their upstream penetration, at various points throughout an estuary. Many of these changes appear in Milford Haven to be concentrated within three distinct regions which are also characterized by changes in the nature of the substratum or the salinity regime. These critical regions occur respectively at about 3, 11 and 15 miles above Thorn Island, and in Fig. 15 they are used to divide the estuary into four zones. The values given here for minimum salinities probably have no particular biological significance, but since they chance to correspond with values used widely to classify brackish waters (see, e.g. Segerstråle, 1959) they are used to designate zones:

Zone I	Oceanic—marine, sandy substrata
Zone II	Marine—polyhaline, mixed substrata
Zone III	Marine—mesohaline, rocky substrata
Zone IV	Polyhaline—mesohaline, muddy substrata

Of the plants and animals included in this survey of Milford Haven, one-half do not pass into zone III and over three-quarters fall short of zone IV (see Table 7).

Zone I occupies the mouth of the Haven and has clean sandy shores and bottom deposits, a salinity which is always greater than 32 ‰ and partial exposure to strong oceanic swell. Its inner boundary represents the natural seaward limit of the estuary, except that it intrudes into the lower Haven at an angle because of the prevalence of south-westerly winds. Silt deposits provide the lower parts of zone II with a mixed bottom and intertidal mud flats; upstream the shores are more rocky. Salinities above Pembroke Dock may fall to 20 ‰, but at high tide are usually over 30 ‰. Above Lawrenny, substrata in zone III are little different but salinities often fall below 20 ‰. Salinity and substratum changes at the junction of the rivers Cleddau make it biologically critical; rock ridges and stones give way to mud and gravel, and the salinity is often as low as 10 ‰. Just within zone IV is the point where salinity changes reach their maximum during one tide or over a neaps-springs cycle. This zone extends to the limit of marine influence, and should perhaps be succeeded, for completeness, by a freshwater zone V.

In comparing this subdivision of Milford Haven with the results of similar work in other areas, difficulties introduced by their often very wide hydrographic, structural and faunistic differences are increased by variations in the nature and completeness of salinity data offered, as well as the types of plants

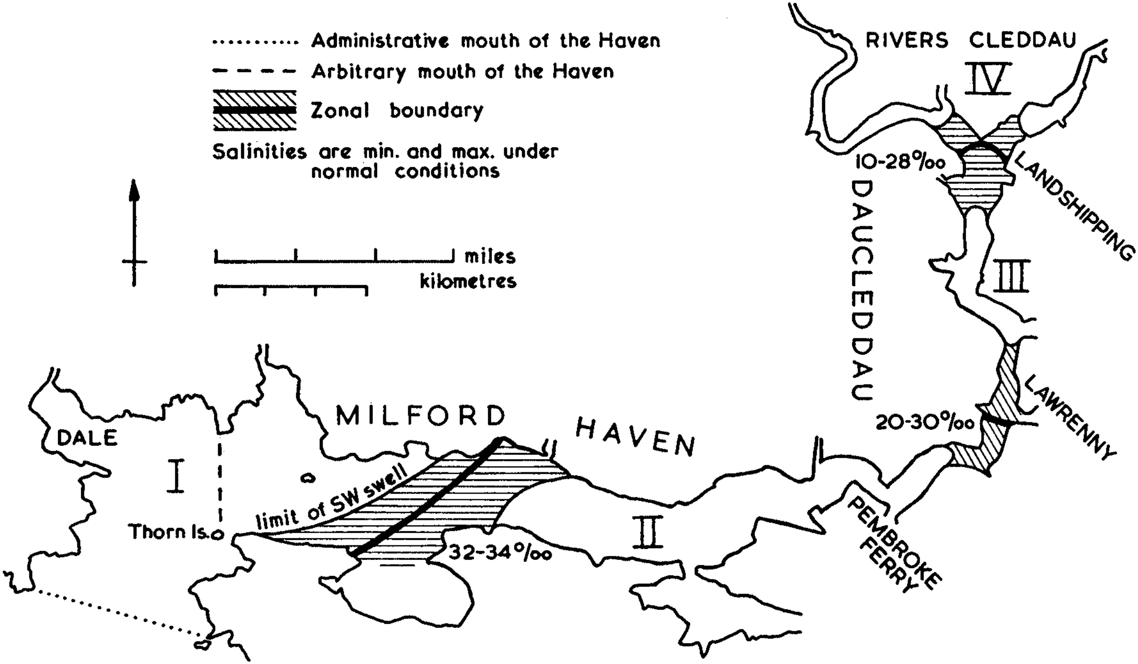

FIG. 15.

Ecological zones in Milford Haven. Each zonal boundary represents a region critical in the distribution of marine plants and animals up the estuary. Zone I is oceanic, with sandy or rocky substrata, while zone IV is largely mesohaline and is muddy. One-half of the marine species studied do not penetrate into zone III, and three-quarters fall short of zone IV.

Table 7. *Estuarine Zones in which some common Intertidal Species reach their Upstream Limits.*

Note that no downstream limits are shown. All the animals and plants listed here were included in an earlier survey of the Dale peninsula (Moyse and Nelson-Smith, 1963).

Zone I

Lichina pygmaea
Fucus vesiculosus evesiculosus
Himanthalia elongata
Laminaria hyperborea
Saccorhiza polyschides
Alaria esculenta
Corallina officinalis
Littorina saxatilis tenebrosa
Patella depressa
P. aspera
Chthamalus stellatus
Balanus perforatus

Zone II

"Verrucaria mucosa"
Porphyra umbilicalis
Laurencia pinnatifida
Gigartina stellata
Rhodymenia palmata
Actinia equina
Spirorbis borealis
S. rupestris
Monodonta lineata
Gibbula umbilicalis
Littorina neritoides
L. saxatilis saxatilis

Zone III

Lichina confinis
Fucus serratus
Laminaria digitata
L. saccharina
Catenella repens
Chondrus crispus
"Lithothamnia"
Spirorbis tridentatus
S. pagenstecheri
Pomatoceros triqueter
Gibbula cineraria
Littorina littorea
L. obtusata
Nucella lapillus
Balanus balanoides
B. crenatus

Zone IV

Pelvetia canaliculata
Fucus spiralis
F. vesiculosus
Ascophyllum nodosum
Littorina saxatilis rudis
L. s. jugosa
Mytilus edulis
Elminius modestus

or animals included in each study. Introductory accounts of the differences in estuarine structure and environmental factors have been given by Day (1951) and Reid (1961). Gillham (1957) studied the distribution of marine and freshwater algae and fringe plants in the estuary of the River Exe, dividing it into marine, brackish and freshwater zones. No part of that estuary corresponds with the oceanic Zone I and in terms of the salinity values quoted, marine algae penetrate for a much shorter distance, probably through a shortage of rocky substrata. Kühl and Mann (1962) divided the lower Elbe into "euhaline" (marine), polyhaline, mesohaline, oligohaline and "limnic" (freshwater) zones, defined similarly to those proposed here, which they related to the distribution of types of zooplankton. Rochford (1951) described four zones in Australian estuarine systems in terms of such criteria as their bottom deposits and the degree of "chlorinity conflict". His marine zone corresponds to that of Milford Haven (zone I). A region of low chlorinity conflict (i.e. little tidal variation in salinity) with high silt deposition (referred to, rather unfortunately, as the "tidal zone") corresponds with only the lower part of zone II, whilst the "gradient zone" of high chlorinity conflict would extend to the end of the present survey. A freshwater zone comprises the rest of the river system. Dahl (1956) discussed many such accounts and distinguished between stable brackish "homoiohaline" waters, such as the Baltic Sea, and the unstable "poikilohaline" waters of graded but varying salinity occurring in tidal estuaries. He showed that both in the transition area between the North Sea and the Baltic, and in a number of estuaries, regions critical for marine animals were found at salinities of 25–30 ‰ and at 15–20 ‰. These correspond approximately to the upper limits of zones II and III in Milford Haven. In Dahl's Transition Area, three-quarters of the marine species fail to penetrate regions with a salinity lower than 30 ‰, and one-half of the remaining euryhaline forms are excluded from those lower than 17 ‰. Ekman (1953) described a similar region at 18–21 ‰ between the Mediterranean and the Black Sea. The greatest reduction in marine species penetrating the Tamar (Percival, 1929) occurs at 25–32 ‰, with a second possible barrier at 15–20 ‰, whilst on passing up the Kola Fjord (Gurjanova *et al.*, 1930) two-thirds of the marine organisms reach a limit between 25 and 30 ‰ and the remaining third between 15 and 25 ‰. Bassindale (1943a, 1943b, 1955) gave data which are not easily summarized, relating the range of salinities and reductions in the numbers of intertidal species up the Severn Estuary, while Doty and Newhouse (1954) noted a reduction in marine species of algae on passing up a New England estuary, but were unable to distinguish critical salinities or readily-defined zones.

SUMMARY

Milford Haven is a deep and rocky drowned valley with a plentiful and varied marine flora and fauna. It has undergone little industrialization until very recently, but has now become a major oil port. The marine ecology of the region was investigated during the earliest stages of this period of industrial development.

The climate is mild and oceanic, but the prevailing south-west winds are often strong and shores around the mouth are exposed to powerful swell. The range of tide, which can exceed 25 feet, increases slightly towards the head of the estuary before diminishing in the rivers. The volume of fresh water entering the Haven is small compared with its tidal volume, so that high salinities may be recorded even in the upper reaches; here the shores are very sheltered but tidal currents are rapid. Mudbanks tend to be local, and the waters contain little suspended material. The estuary is essentially unpolluted except by occasional oil spillages; the biological effects of oil pollution are considered briefly. There is evidence of a net circulation in which saline waters move upstream along the bottom, balancing a downstream flow of surface waters; vertical stratification is marked in the upper reaches.

The influence of such environmental factors as variations in salinity upon the distribution of marine plants and animals is briefly discussed. A subdivision of Milford Haven into ecological zones is proposed, based on the changing salinities and substrata, and reflected in the distribution of marine species. This scheme is compared with those of workers in other similar localities.

ACKNOWLEDGEMENTS

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