SALINITY STRUCTURE AND TIDAL FLUSHING OF THE FLEET

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INTRODUCTION

The Fleet is truly estuarine in character, ranging in salinity along its length from marine salinities at the mouth to almost fresh water at Abbotsbury from time to time. This is not surprising since although it is connected to the open sea by such a small mouth, it has already been pointed out, by Robinson (ibid) how the tides dominate the water movement in the lagoon. The comparatively large volume of tidal exchanges into and out of the Fleet, particularly at Spring tides, ensure that salt is flushed in and the comparatively small fresh water inflow and land runoff is not sufficient to wash out the salinity. However, it will be shown how the salinity structure varies under different conditions of tide and precipitation. This is important for the ecology of the estuary, and also provides a valuable indicator with which to estimate residence times and flushing rates for different parts of the estuary under different conditions, using a mathematical model tuned to fit the salinity observations.

SALINITY STRUCTURE

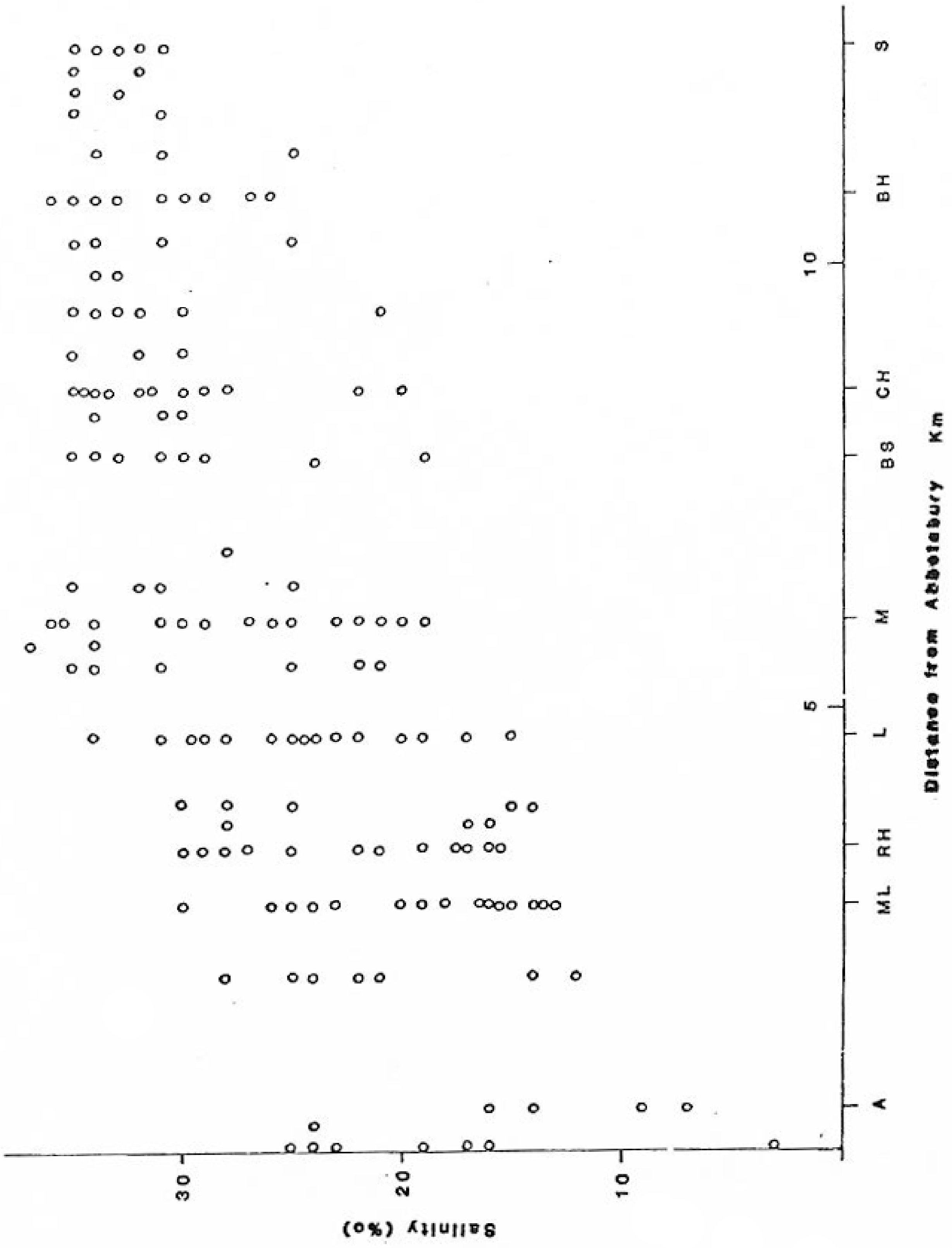
Observations of salinity have been made by various workers since 1967. Further details of these are reported by Whittaker (1980) and Robinson (1981). Figure 9 shows all the observed salinities plotted against the distance along the Fleet and indicates the wide variation of conditions which can occur. However, fig.10 selects the profiles typically appropriate to (a) drought, (b) high precipitation and (c) average runoff conditions. In these a pattern emerges with the salt penetrating further towards Abbotsbury as the freshwater input decreases. What is also apparent is that the salinity does not vary linearly with longitudinal distance, but there tends to be a length of about four or five kilometres over which most of the variation occurs. This region of steep salinity gradients moves towards or further away from the mouth as the run off increases or decreases. Under all but the most torrential rainfall conditions, marine salinities penetrate virtually undiluted into Littlesea and are recorded as far as Chickerell Hive. Under drought conditions the marine salinity penetrates beyond Moonfleet, and only drops to about 25‰ at Abbotsbury, whereas with high runoff it has already drooped to 20‰ at Moonfleet and continues falling to around 5‰ at Abbotsbury.

The longitudinal profile also depends on the fortnightly Spring neap tidal cycle as figure 11 clearly shows. These observations were made seven days apart in the summer of 1980, a season of average rainfall. The salinities at either end are not appreciably influenced by the tidal conditions, but the region of steep gradients shifts towards the mouth during neap tide conditions, and fresh water penetrates more noticably towards Littlesea. This clearly illustrates the major part played by tidal exchange in flushing salt water in and fresh water out. As pointed out previously the tidal mean level and hence volume of water in the West Fleet is considerably greater during Spring tides than at Neap tides, and with an increase also of the tidal prism at Spring tides the flushing effect is able to penetrate much further towards Abbotsbury. The Spring-Neap fluctuations and the variation due to rainfall conditions occur over similar timescales, so that it is often difficult to distinguish their separate effects. Thus whilst one expects the West Fleet to become saltier during Spring tides, a spell of heavy rain may in fact decrease the salinity. It has only been possible to present the effects separately in figures 10 and 11 by averaging out the tidal effects in figure 10 and choosing a period of steady precipitation for figure 11.

As well as these longer period fluctuations, the salinities at a point also vary within the $12\frac{1}{2}$ hour tidal cycle. This is principally due to the advection of the longitudinal salinity structure by the tidal oscillations past an observer at a particular station. The amplitudes of salinity oscillation will be greatest where the longitudinal gradient is steepest, for a given tidal oscillation. Salinity is of course at a maximum when the tidal excursion is at its furthest from the mouth, ie at approximately high water. However, at neap tides, the tidal movements are virtually non-existent in the West Fleet, and so even strong salinity gradients there do not give rise to semidiel salinity fluctuations. This is illustrated in figure 12 where the amplitude of semidiel salinity oscillations is plotted against position along the Fleet, for spring and neap tides under high and low rainfall conditions. The Spring tide amplitudes reflect the position of maximum longitudinal salinity gradients in figures 10 and 11 whereas the neap tide oscillations are much smaller in the West Fleet, but much greater in Littlesea and the Narrows when high runoff has pushed the salinity gradients seawards.

There is also a small amount of lateral variation of salinity observed by transect surveys in winter 1967 and summer 1979. The details are reported

Fig 9


Salinity (%o)
30
20
10
Distance from Abbotsbury Km
5
10
A
ML
RH
L
M
BS
CH
BH
S

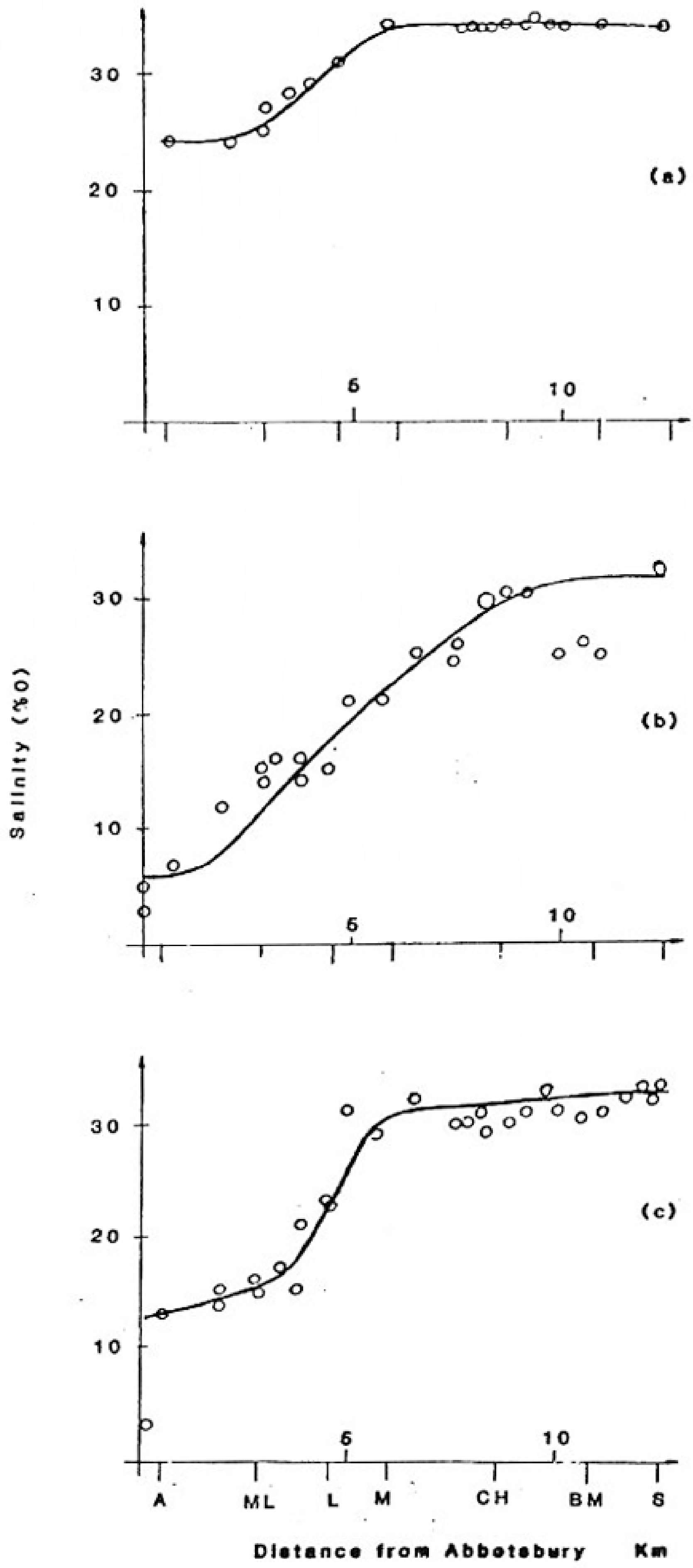

30
20
10
5
10
(a)
30
20
10
5
10
(b)
Salinity (%0)
30
20
10
5
10
(c)
A
ML
L
M
CH
BM
S
Distance from Abbotsbury Km

Fig 11

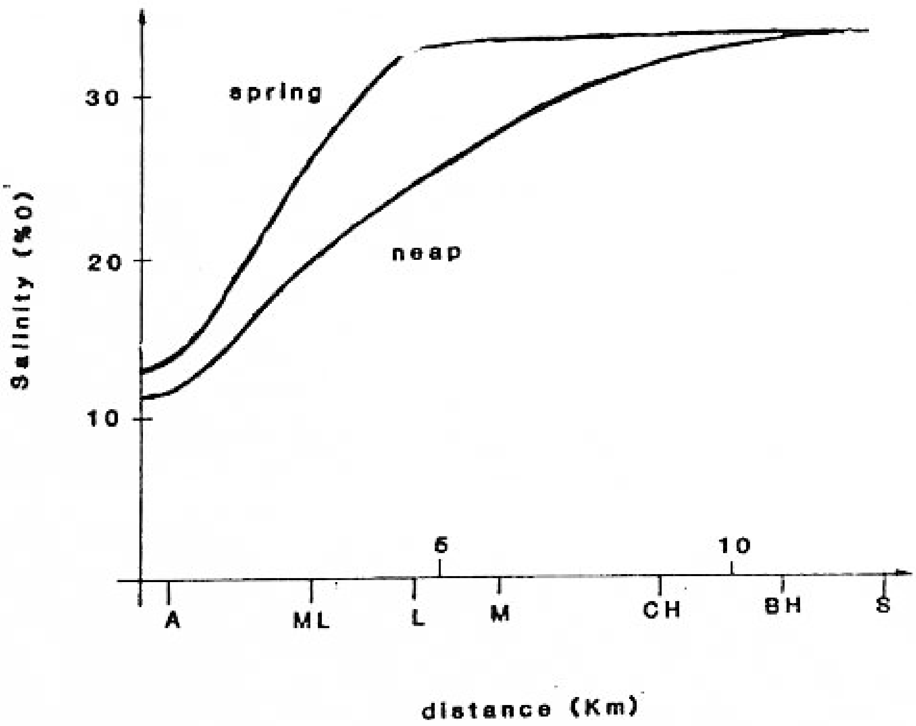
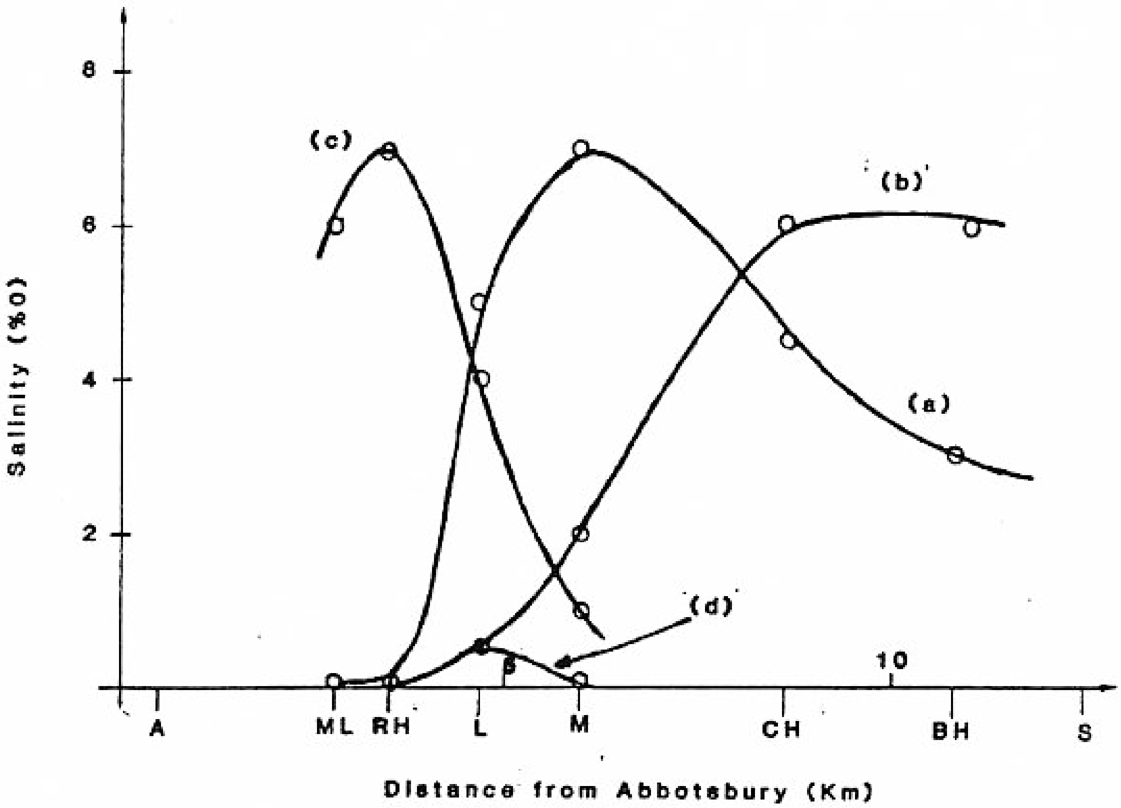

spring
neap
30
20
10
Salinity (%0)
6
10
A
ML
L
M
CH
BH
S
distance (Km)

Fig 12


8
6
4
2
Salinity (%0)
(c)
(b)
(a)
(d)
10
A
ML
RH
L
M
CH
BH
S
Distance from Abbotsbury (Km)

by Whittaker (1980) and Poulter (1979), but figure 13, showing the salinity at three stations across the Fleet opposite Langton Hive, is typical of other transects.

SEEPAGE THROUGH CHESIL BEACH

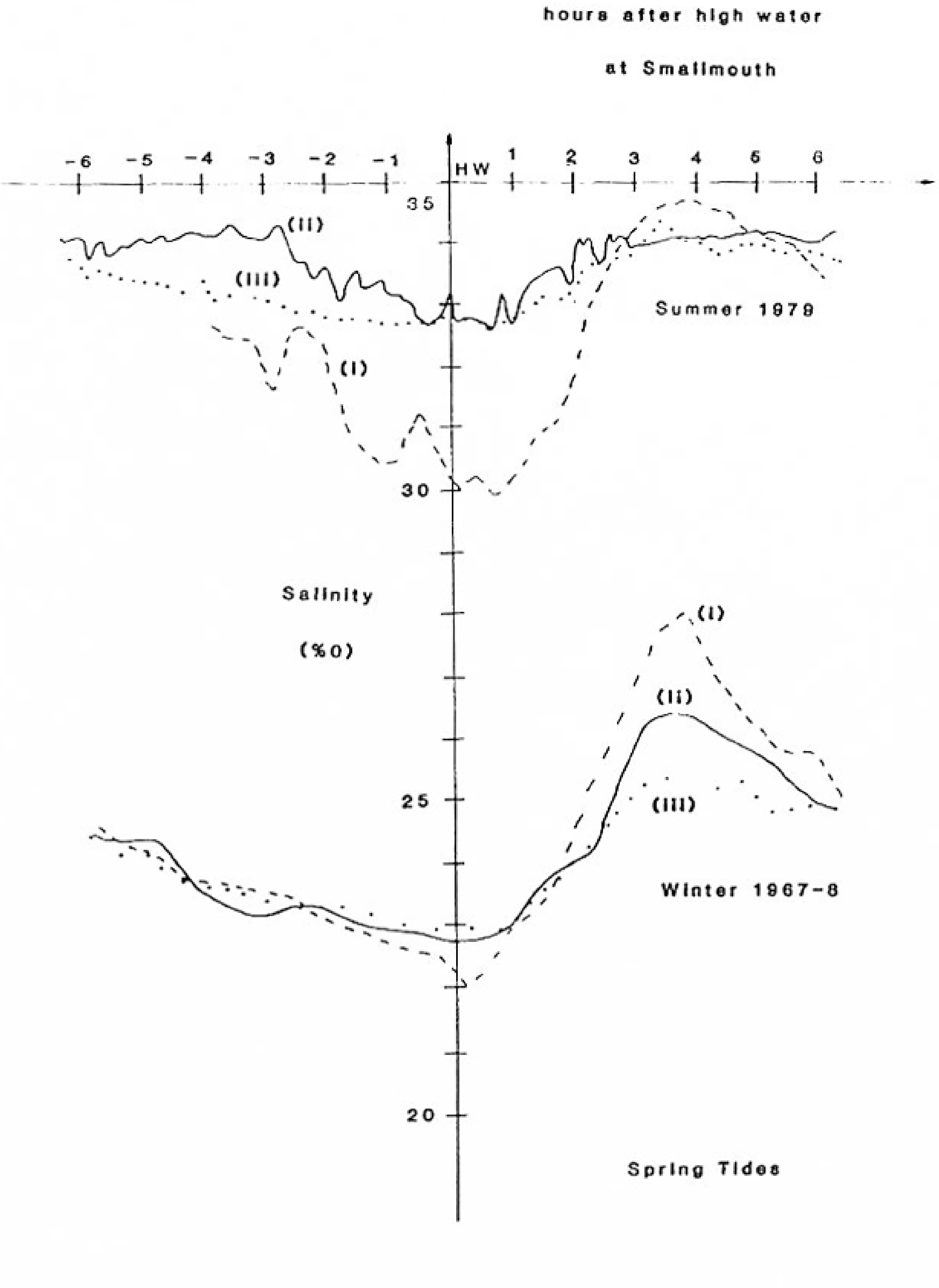
Steepage of sea water through Chesil beach undoubtedly occurs. Indeed at times of high water in West Bay it is possible to see water trickling out of the beach, and in times when the sea level is particularly high due to storm tides and wave set up, the sea water pours through porous passages in the beach at a fairly high level, known locally as "the cans". Some observers in the past have considered that this seepage is a major component of the circulation. Indeed the winter 1967 survey shown in figure 13 indicates an increase in salinity towards the Chesil beach side, and might be considered to confirm that seepage of salt water through the beach is significant for the salinity structure, and hence the circulation. However, apart from the most extreme conditions of storm tides, the volume of water seeping through the beach is probably very small and unimportant to the circulation. Closer inspection of the 1967 data in comparison with summer 1979 records in figure 13 confirms this. The winter survey shows the lateral gradient of salinity increasing towards Chesil beach at high tide only (high tide at Langton occurs between three and four hours after high tide at Smallmouth - (Robinson, ibid). At low water there is a slight gradient in the opposite sense, and this is at the time when the tide is high on the other side of the beach and seepage should be at its strongest. The summer survey shows very little gradient at high water, but a strong decrease of salinity towards Chesil beach at low water, certainly not indicative of seepage occurring. The probable explanation of the lateral variation is that the deepest channel and easiest flow of water is along the Fleet adjacent to the beach. Thus the beach side experiences the greatest tidal fluctuations of salinity as water is advected up and down the Fleet, whilst on the landward side the water is not so readily exchanged longitudinally and the salinity fluctuates less. In the winter, freshwater runoff from the land tends to maintain this side at a lower salinity when high salinity water advects Westward along the beach side at high water. In summer there is little runoff, and the high water temperatures probably lead to evaporation and consequently enhanced salinities on the landward side. Thus lateral gradients of salinity are probably due to land runoff, and the trapping effect of embayments and shallow Zostera beds on the landward side rather than seepage through the beach. Care must therefore be taken when interpreting salinity measurements made on the landward shore which may not be typical of salinities across the whole section at that location along the Fleet.

FLUSHING AND RESIDENCE TIMES

From the observations discussed above, it becomes clear that the salinity structure is the result of the balance between tidal diffusion of salt inwards, and river runoff washing it seawards. Because there is no appreciable vertical stratification of salinity, there can be no significant vertical circulation which is the mechanism for flushing out some estuaries. Neither can lateral circulation play much part because of the narrow constrictions occurring along the length of the Fleet. The freshwater runoff per tidal cycle at times of high rainfall, is about 1/50 of the minimum low water volume of the whole Fleet, so that if no tidal flushing occurred the residence time of water throughout the Fleet would be at least 25 days, and in times of drought about twenty times longer with runoff 1/20 of the maximum. However, the regular tidal exchange of water between the Fleet and Weymouth Bay ensures that the East Fleet is rapidly flushed out within one or two tidal cycles. As the tidal influence decreases towards Abbotsbury, the flushing time increases.

In order to quantify the expected residence time of water in the West Fleet, a mathematical model of the tidal exchange and river run-through processes has been constructed, and predictions of the salinity distribution under different tidal and runoff conditions have been compared with the observed values to validate the model (see Robinson, 1981). The model has been used to estimate the time taken for the water in a particular section of the Fleet to be flushed out until only 10% of the originally identified water mass remains in the section. It is assumed that once a marked element of water leaves the Fleet at Smallmouth, it is not returned on the flood tide. Figure 14 shows how the number of tidal cycles to achieve this degree of flushing varies with location along the Fleet, and also varies with both the type of river runoff conditions and to a lesser extent with the stage during the Spring-neap cycle from which the flushing time is calculated. As expected, in the East Fleet, the water residence time is very short, and is independent of rainfall conditons, but West of Moonfleet the flushing time rises sharply and is much more dependent on river flow conditions. This is because the tides are much less efficient and flushing depends more on the throughflow of stream water. The model indicates that at Abbotsbury, the flushing time may be as much as 40 days under drought conditions, and even with heavy rainfall is as long as 10 days. These are of course only model predictions, and remain to be tested by observations, but the success of the model in predicting the salinity structure suggests that these estimates are realistic. It may seem surprising that the flushing time calculated from a time midway between neap and spring tides is longer, in certain parts of the Fleet, than that measured from a time midway between spring and neap tides. The former

Fig 13


hours after high water
at Smallmouth
-6
-5
-4
-3
-2
-1
HW
1
2
3
4
5
6
35
30
25
20
(II)
(III)
(I)
Summer 1979
Salinity
(%0)
(I)
(II)
(III)
Winter 1967-8
Spring Tides

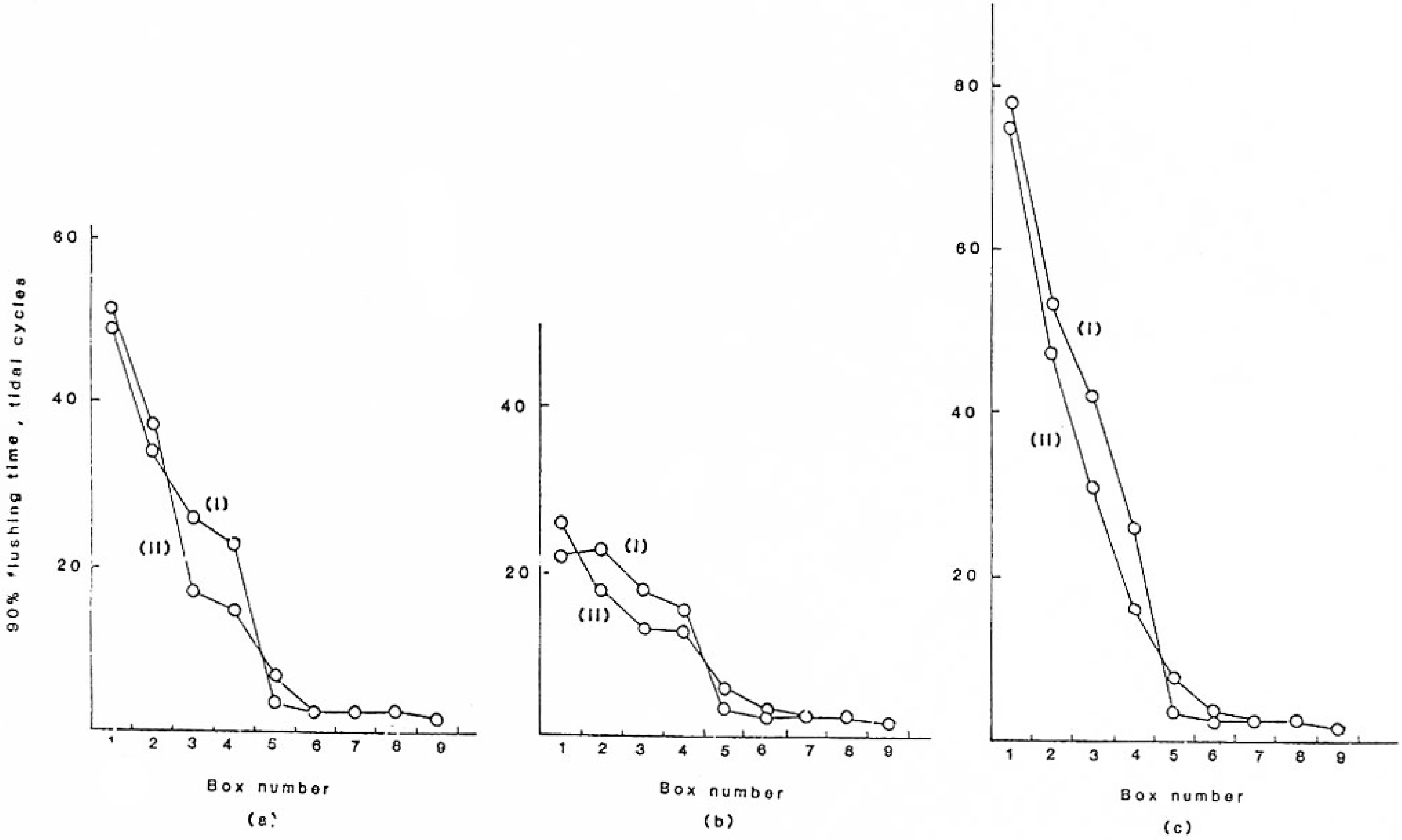

90% flushing time, tidal cycles
Box number
(a)
Box number
(b)
Box number
(c)
(I)
(II)

Fig 14

has the benefit of the spring tides to enhance flushing, and might be expected to be less. However, the spring tides also result in an overall increase of tidal mean water volume in the West Fleet, so that in fact the flushing effect of the rivers is inhibited by the spring tides pressing water westwards. Moreover, the model indicates that water labelled at, say, Langton as the tidal range is increasing is flushed inwards by the spring tides and is only slowly released past Langton during the Neap part of the cycle.

The model results have implications for the biochemistry of the water mass and indicate that pollution of the West Fleet by natural or artificial processes would not be rapidly cleansed by the natural circulation. The distribution throughout the Fleet of water from a particular stream can also be modelled, and as expected shows that the quality of water in the Abbotsbury Brooks has an important influence on water quality in the West Fleet. The Langton Brook has a significant effect, but stream inputs east of Moonfleet, unless they were to contain an extremely noxious pollutant, are predicted to have negligible effect on the water quality in the Fleet.

CONCLUSION

The Fleet may be broadly divided into two distinct regions. Seawards of Moonfleet, the salinities are close to marine values, with appreciable freshening only when river runoff is high. At all times the water is well-exchanged with the sea outside and as long as the tidal conditions remain as they are the water should be rapidly flushed out and replenished. West of Moonfleet the salinity rapidly decreases, and becomes more variable with both rainfall and tidal state. The water exchange rates become much slower and pollution problems due to prolonged residence of effluents become more likely to occur towards Abbotsbury.

Seepage through Chesil Beach is not thought to contribute significantly to the circulation and flushing, although a breach in Chesil Beach, or the more likely event of continuous operation of the cans at the Abbotsbury end during storm tide conditions in West Bay will result in a rapid flushing out of the West Fleet. Apart from these exceptional events, it is believed that the normal flushing processes are now well enough understood to provide the physical basis of ecological studies.

Acknowledgements The work summarised in this paper has only been made possible by the co-operation of the Strangways Estate and their staff, who have given every assistance in fieldwork programmes and access to the Fleet, and by the willingness of the C.E.G.B. to make the data of their surveys available for scientific analysis. Dr John Whittaker has also made his salinity data freely available. The author gratefully acknowledges the assistance of Mr Paul Riddy and Mr Philip Poulter in the fieldwork and processing of data, Mrs Linda Warren in aspects of the modelling and several students in the Department of Oceanography who helped with fieldwork.