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THE *SEA EMPRESS* INCIDENT AND THE LIMPETS OF FRENCHMAN'S STEPS

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ABSTRACT

Oil spilled from the tanker *Sea Empress* into Milford Haven in February 1996 appeared, in April 1996 to have severely affected the limpet population at Frenchman's Steps. Overall densities were lower than in previous years, with especially noticeable declines in smaller size classes on the lower half of the shore. As a result, the modal size for the population rose from the 10-14.9mm to the 15-19.9mm bracket. Data collected in July and October 1996 showed the population recovering and densities approached normality in April 1997. Such a rapid recovery suggests recruitment into the 'visible population' from arrested-growth juveniles from earlier years that survived the oil in deep crevices. Successful settlement of spat in the winter of 1997/98 saw the population structure return to normality, with the modal size class back at 10-14.9mm, in April 1998.

INTRODUCTION

Dale Fort lies at the tip of a small promontory on the south side of Dale Roads, near the mouth of the Milford Haven. Frenchman's Steps is the only place along the shores of Dale Roads, between the Fort and Dale village, where it is possible to land and climb the low cliff (Fig. 1). They were reputedly used by the crews of French crabbers, coming ashore to sell some of their catch in exchange for provisions.

Dale Fort Field Centre was established in 1947 and its adjacent rocky shores rapidly became well-known sites for the study of rocky shore organisms and inspired the production of *Collins Pocket Guide to the Seashore* (Barrett & Yonge, 1958). Within a decade, interest concentrated on zonation patterns and their variation in response to differing levels of wave action. These shores are the type location for Ballantine's (1961) *Biologically-defined exposure scale for the comparative description of rocky shores*. Moyse & Nelson-Smith (1963) described the zonation patterns before the 1963 cold winter and the advent of the oil industry.

Fears about the effects of oil pollution on the shores of Milford Haven have been voiced for forty years (see, Dudley, 1968, in response). There have been many small-scale incidents – some of which provided material for research projects (e.g., Petpiroon & Dicks, 1982) / teaching exercises (Iball & Crump, 1982) – and two or three more serious ones[1]. But nothing had prepared the local authorities, let alone FSC staff, for an event on the scale of the *Sea Empress* spill in 1996.

Limpets of the genus *Patella* are, arguably, the most important organisms on European rocky shores for it is their differential grazing activities that produce the patterns used by Ballantine in his exposure scale. It follows that anything which affects the distribution or abundance of limpets has far-reaching effects on the sea shore as a whole. At Frenchman's Steps, the common limpet is *Patella vulgata* L.

[1] The second of which, *Chryssi P. Goulandris* on 13th January 1967, had two long-lasting effects for it was directly responsible for Eric Cowell founding of the Oil Pollution Research Unit at Orielton Field Centre (see Baker, 1987, and Dicks, 1987) and, most significantly for *Sea Empress*, the ban on damaged, leaking tankers entering the Port of Milford Haven. (Ed.)

THE INCIDENT

The *Sea Empress* released approximately 72,000 tonnes of Forties Blend crude oil and about 360 tonnes of heavy fuel oil in the period 15th to the 21st February 1996, when it grounded near the mouth of the Milford Haven waterway and while it was on an oil refinery jetty. Some more oil leaked when it was on passage to Belfast.

The tanker grounded on Thursday the 15th of February, at approximately 20.07 hours, in calm weather, one and a half hours before low water. The weather remained calm while various parties prevaricated over whether to pump oil off then and there, take the tanker into the protected waters of the Haven or tow her out to sea, away from one of Britain's most important marine wildlife sanctuaries, thereby minimising the potential environmental impact. Meanwhile the tanker remained where it was, leaking oil.

Two days later, gale force winds broke the tug lines and anchor chains and the vessel was impaled on the rocks near St. Ann's Head. Between the 17th and 21st of February, a number of spectacularly unsuccessful attempts were made to do something positive about what was rapidly becoming an environmental catastrophe. On the evening high tide of the 21st, the *Sea Empress* was re-floated and transferred to a jetty inside the Haven, where she continued to leak oil. On Saturday the 24th of February, nine days after the initial incident and after 70,000 tonnes of oil had been lost, pumping was finally started to remove the remaining oil from the vessel.

The incident was the subject of a Marine Accident Investigation Branch (MAIB) enquiry. Many people feel that the extent of the disaster was enough to justify a full Public Enquiry.

CHEMICAL DETAILS OF THE OIL

Sea Empress was carrying Forties Blend, a blend of crude oils which feed into the Forties pipeline in the North Sea. This a light oil and at least one third would be expected to evaporate from the sea during the first 24 hours.

The oil rapidly combined with water to form a 70% water-in-oil emulsion or "Mousse". This combination of 70% water and 30% oil will, inevitably, have more than three times the original volume of the oil. Emulsification, as a process, is sensitive to weather conditions at the time of the spill and the subsequent sea state.

The heavy fuel oil is, as its name suggests, a heavier form of refined oil used to power the ship. It is more viscous than the crude oil and so neither evaporates, disperses nor forms an emulsion very readily. It is far more persistent in the environment and much more resistant to natural and human clean-up processes; therefore, its impact has been far greater than the small volume would suggest.

THE EFFECTS OF OIL ON ROCKY SEA SHORES

The vulnerability of a rocky shore to oil pollution depends on its topography, composition, exposure to wave action and geographical location. Other variables include the type of oil, and therefore it's toxicity and viscosity, how much was spilt, the season and weather at the time of the spill, the duration of exposure to the oil – which, in turn, will depend on local current conditions, tidal height and position on the shore. Any attempt to write about the effect of oil on rocky shores leads to over simplification.

It is still, however, possible to make some generalisations. Wave-exposed rocky shores tend to self-clean more rapidly than sheltered ones. It is possible for an exposed rocky shore to have no visible traces of oil left after as little as two years; very sheltered shores may still have oil remaining more than twelve years after the original spill (Moore & Guzman, 1995).

Brown seaweeds are relatively insensitive to oil due to the slimy mucilage which coats all their surfaces. Even after heavy oiling, most of these seaweeds are washed clean and remain largely undamaged. (They are more likely to be damaged by dispersants – see Boney, 1968).

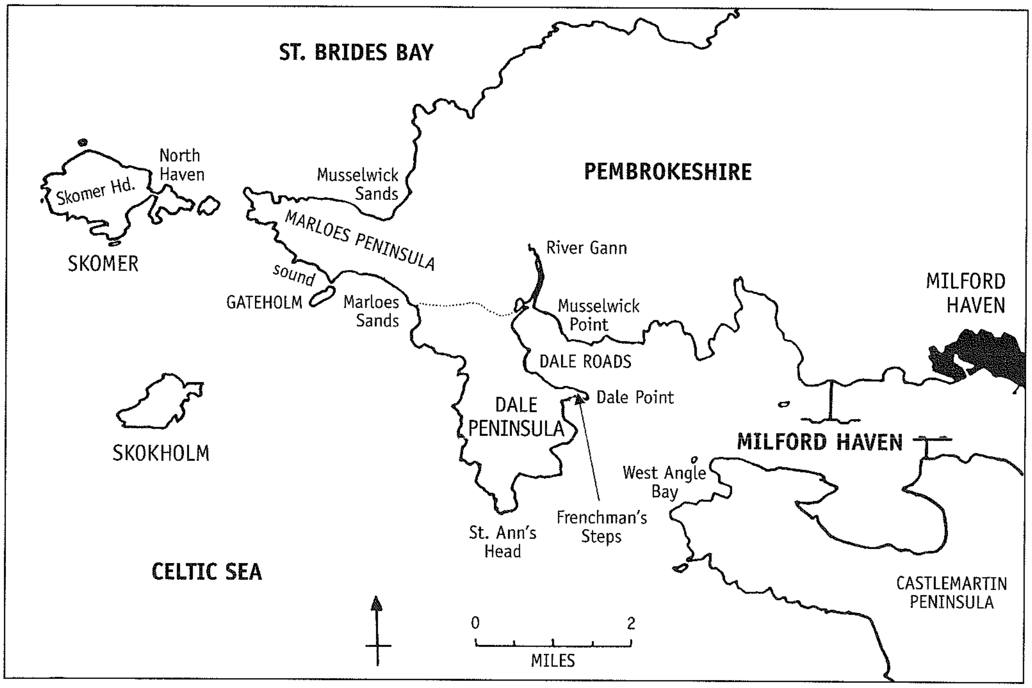

FIG. 1. The entrance to Milford Haven, showing some of the places mentioned in the text.

Barnacles and inter-tidal anemones are, typically, only killed after being smothered with oil for more than one tidal cycle. Limpets, periwinkles, topshells and other grazing molluscs are usually more susceptible and toxic oil may kill large numbers of them. Death may either be a direct effect of the oil or the animals may be narcotised, thereby losing their grip on the rocks which in turn makes them vulnerable to predation and desiccation. (For more detail see Archer-Thomson, 1979.)

The removal of large numbers of grazing herbivores is often followed by a rapid proliferation of green algae which cover the rocks with a "green flush". This is a characteristic sign of a stressed rocky shore community and typical of the first signs of recovery after oil pollution (see Crump, Morley & Williams, 1998). As long as the shore is not contaminated with more oil, the spores of macroalgae will settle and the short-term result is often a seaweed-dominated shore. Subsequently, juvenile limpets and other snails, benefiting greatly from the increased food supply, will soon colonise the site and gradually repopulate the vacant areas.

Intertidal detritivores, such as sandhoppers which live amongst seaweed and under boulders, are often killed, thus slowing down the essential process of nutrient recycling. Crabs and starfish may also be affected, reducing the predation pressure on the herbivores and filter feeders which benefit accordingly. However predator numbers usually recover very quickly and often within a year. Exceptions can occur when oil is trapped on the shore for a long time and if long lived, slowly repopulating, species are affected. Dogwhelks are a case in point. They may ingest lethal amounts of oil from their usual food source, namely barnacles and mussels. Since dogwhelks do not have planktonic young they can only recolonise the shore very slowly from the horizontal migration of surviving individuals.

Oil pollution can also have sub-lethal effects, including reduced growth rates and loss of reproductive ability. Other changes in invertebrate biochemistry have been observed and studied in a variety of rocky shore species. However, the extent of such sub lethal effects on rocky shore communities remains largely unknown.

EFFECTS OF THE *SEA EMPRESS* OIL AS REPORTED IN SEEEC, FOE ETC.

Extent

Around 200km of coastline were affected by the spill and the coastline within the Milford Haven waterway was heavily oiled. Some oil travelled as far east as Pendine Sands in Carmarthen Bay. Some oil reached Skomer Island, no oil was observed north of St. David's Head. Lundy Island in the Bristol Channel received light oiling, some pellets of oil reached the Irish coast.
The *Sea Empress* spill is now widely quoted as being the third largest spill in UK waters although volume is not necessarily a reliable indicator of environmental impact.

Treatment

Some oil was recovered mechanically at sea. Between the 17th and the 25th of February, 445 tonnes of chemical dispersants were used to reduce the risk to the coastline and to birds at sea. Dispersants were not used within 1km of the shoreline.

Beaches were cleaned using mostly mechanical methods but dispersants were used near selected beaches e.g. Tenby where the amenity value was judged to take priority.

Rocky Shores

The SEEEC (1996) initial report described heavy limpet mortality, ranging from 5% to 50% generally, including the Dale Peninsula (information supplied by Dale Fort staff), but from one site in West Angle Bay 90% mortality was recorded (see Crump, Morley & Williams, 1998). There have been significant effects on periwinkles, barnacles and sea slaters. Pink coralline encrusting algae have been extensively bleached in some areas. Fewer than 20, of the previous 150 strong population, of the cushion starfish *Asterina phylactica* remained in West Angle Bay, the type locality for the species.

The Friends of the Earth, Lost Treasure, report (1996) describes red algal damage and increased amounts of brown algae in the strandlines around the coast. Heavy limpet mortalities were described from walk-over surveys.

DALE FORT RESEARCH AND FIELD OBSERVATIONS

General Observations

At the time when most of the Sea Empress oil was coming ashore, winds on the Dale Peninsula were generally off-shore. Consequently, damage to local shores was not as extensive as for West Angle Bay in particular and South Pembrokeshire in general. Any conclusions as to the impact of the oil on local rocky shores should take this into account.

There follows a small sample of the many field observations taken from local rocky shores shortly after the oil spill. The material is included to give an impression of what working conditions were like and to include some of the qualitative information that was gathered at the time.

Black Rock. (SM 813060) 21st March 1996.
"Upper shore worst affected. A shiny coating of oil noticed on all upper shore macroalgae. Upper Shore and some of the Splash Zone lichens looking very dull. Fewer rough periwinkles seen and they appeared lower down the shore than usual. Fewer beadlet anemones than normal. Deposits of oil in cracks and crevices all over the shore."

Castlebeach. (SM 818050) 22nd March 1996.
"A truly depressing experience. The strandline was a mass of oiled seaweed. All the pebbles below this spring tide strandline had a shiny film of oil all over them as did the rocks either side. There was a great deal of oil in most of the rock pools. The rockpool we started the transect from was badly oiled and virtually lifeless. Red seaweeds, the few that remained, were brown with oil. In contrast to Black Rock, here the Lower and Middle Shore seemed worse."

"All the field equipment, including tapes, quadrat poles, dichotomous keys and waterproof clothing had to be washed on our return to the Centre. A south easterly wind blew more oil in and there was a shiny film of oil from Castlebeach out to Dale Point."

Point Wood Beach. (SM 821053) 23rd March 1996.
"Globs of oil all over the shore. A student accidentally, and very gently, nudged a limpet and the shell fell off leaving the animal naked and vulnerable. This somehow seemed worse than anything else we had seen and caused universal sadness and revulsion throughout the group. Topshells seen lying dead around small patches of crude oil. Usual shiny film over the rocks and seaweeds. I abandoned work on my usual periwinkle site 7 as conditions were too depressing and disgusting to continue. Waterproofs and equipment covered in oil and I'm very depressed at what has been done to one of my research sites. A small sheltered inlet to the east of the periwinkle site had a blanket covering of crude oil over the Middle and Upper Shore."

29th April 1996.
"Far less oil on the periwinkle site and the local sheltered shores in general. Still some. Castlebeach strandline still disgusting. Some limpets falling off the rocks when touched."

Castlebeach. 14th April 1996.
"Waterproof pebbles again. Most of the extremely badly oiled material in the strandline has been removed by the Council. Signs of bleached *Lichina pygmaea, Corallina* spp., *'Lithothamnia'* and barnacles. Found a white *Eulalia viridis**, could this be an oil effect?"

Point Wood Beach. 15th April 1996.
"Shore looks better but the east side of site 7 still quite badly oiled. Pepper Dulse, (*Laurencia pinnatifida*) has a substantial amount of *Enteromorpha spp.* growing on it, I've never seen that before. The Middle and Lower Shores around the Fort have the characteristic "green flush" of green algae all over them that is typical of the early recovery stages after an oil spill."

17th June 1996.
" A large bed of Egg Wrack, *Ascophyllum nodosum*, the longest-lived seaweed on British shores, has been accidentally cleared i.e. destroyed by Council workers. On the first 50m of shore (all that I have looked at so far) there is approximately a 90% adult barnacle mortality. There seem to be very few flat periwinkles."

Subsequent observations confirmed that this was the case on all the local shores but the barnacle settlement was so spectacular that, in September 1996, the barnacle population seemed to have recovered, albeit with a rather different age structure. Flat periwinkles seemed to recover well in the latter part of June and early July. A feature observed throughout 1996, was the abnormally large numbers of empty limpet shells washed up on all the beaches around Dale Fort.

In October 1996, with the advent of some particularly strong gales, one gusting hurricane force, some oil was mobilised from the sea bed and beach sediments.

Quantitative Work with Limpets

This extensive introduction is provided to set in context the quantitative investigations of a limpet population, carried out by students from Dale Fort Field Centre over a number of years.

* *Eulalia viridis* A, normally green, polychaete worm that lives amongst barnacles on rocky sea shores [Ed.]

MATERIALS AND METHODS

The site chosen was Frenchman's Steps, Grid Ref. SM 822053. This is a sheltered rocky shore, with a north-north-easterly aspect, Ballantine Exposure Grade 4.

Data were collected by groups of students attending field courses at Dale Fort Field Centre. An interrupted belt transect, sampled at 75cm vertical height intervals, was established from a starting height at 2.25m* above Chart Datum, up the shore until the upper distribution limits of limpets were reached. 50cm by 50cm quadrats were placed at 50cm (horizontal) intervals along a tape measure laid out at each height. In each quadrat, the longest diameter of every limpet was measured and recorded, in its appropriate 5mm size class, on recording sheets provided. To prevent the measurement of the same limpet more than once, each shell was lightly marked with chalk after it had been recorded.

The number of groups involved with each survey varied with class size. The results quoted in this report have been standardised to give totals for ten quadrats at each height. No changes have been made to the methodology used to collect the data, over the years, to facilitate comparisons with past data.

RESULTS AND ANALYSIS

Table 1 gives the numbers of limpets found in ten 50cm x 50cm quadrats at the seven heights up the shore, according to the season and year in which they were counted. Divide these totals by 2.5 to obtain densities m^{-2}.

Table 2 similarly provides the data on size frequencies. Tables 3-5 present a summary of the statistical tests carried out to compare comparable counts/measurements in different years.

TABLE 1. *The number of limpets found in 10, 50cm x 50cm quadrats at each 75cm vertical height interval up the shore at Frenchman's Path.*

April Data	Vertical Height above Chart Datum in metres						
	2.25	**3**	**3.75**	**4.5**	**5.25**	**6**	**6.75**
Year							
1985	191	504	693	556	333	49	0
1986	152	407	480	338	228	55	0
1989	487	600	607	556	241	94	0
1996 (1)	72	177	335	313	248	75	5
1996 (2)	26	174	320	346	264	36	0
1997	64	330	432	519	235	145	0
1998	143	642	698	558	300	100	0

July Data	Vertical Height above Chart Datum in metres						
	2.25	**3**	**3.75**	**4.5**	**5.25**	**6**	**6.75**
Year							
1985	182	434	601	535	299	55	0
1987	259	398	447	441	324	25	0
1989	310	484	507	477	257	91	0
1996	188	263	260	308	235	103	0

* where the bed rock starts. The lower shore is gravel.

October Data	Vertical Height above Chart Datum in metres						
	2.25	**3**	**3.75**	**4.5**	**5.25**	**6**	**6.75**
Year							
1985	102	282	363	383	253	32	0
1986	147	204	225	246	237	36	0
1987	259	486	730	464	364	41	0
1995	154	228	229	313	253	62	1
1996	133	420	510	398	300	43	0

TABLE 2. *The number of limpets in each size class found on the transect up the shore at Frenchman's Path. There were no limpets larger than 65mm measured.*

April Data	Size Class (mm)												
	<4.99	5.0-9.99	10.0-14.99	15.0-19.99	20.0-24.99	25.0-29.99	30.0-34.99	35.0-39.99	40.0-44.99	45.0-49.99	50.0-54.99	55.0-59.99	Total
Year													
1985	96	475	658	494	327	171	72	18	13	1	1		2326
1986	55	239	438	410	266	145	67	27	10	3			1660
1989	324	586	590	469	240	200	108	41	14	14			2586
1996 (1)	33	157	285	327	221	94	72	19	11	5			1224
1996 (2)	8	91	248	376	286	115	29	8	3	1			1165
1997	19	172	360	472	359	187	112	34	6	3	1		1725
1998	195	479	585	494	407	170	78	22	10	1			2441

July Data	Size Class (mm)												
	<4.99	5.0-9.99	10.0-14.99	15.0-19.99	20.0-24.99	25.0-29.99	30.0-34.99	35.0-39.99	40.0-44.99	45.0-49.99	50.0-54.99	55.0-59.99	60.0-64.99
Year													
1985	111	409	577	454	293	141	84	17	11	6	2	1	
1987	79	290	496	440	336	117	79	32	19	3	2	1	
1989	87	311	484	484	369	180	107	61	27	9	6		1
1996	28	105	270	390	243	160	83	50	25	3			
1998													

October Data	Size Class (mm)												
	<4.99	5.0-9.99	10.0-14.99	15.0-19.99	20.0-24.99	25.0-29.99	30.0-34.99	35.0-39.99	40.0-44.99	45.0-49.99	50.0-54.99	55.0-59.99	60.0-64.99
Year													
1985	53	187	387	347	257	105	57	12	10	2			
1986	68	145	237	232	199	98	64	27	13	8		2	2
1987	71	343	701	509	330	189	110	53	29	10			
1995	84	152	254	250	237	100	74	46	32	6	3	2	
1996	13	210	435	495	388	178	38	25	15	3	5		

TABLE 3. *Statistical summary for limpet numbers at the measured heights up the shore.*

April Data	Wilcoxon Matched Pairs Test						
Years	Result	Years	Result	Years	Result	Years	Result
96(2) / 89	10%	96(2)/ 86	ns	96(2) / 85	SIG	96(2)/96(1)	ns
96(1) /89	10%	96(1) / 86	ns	96(1) / 85	10%	97 / 96(2)	10%
97 / 89	ns	97 / 86	ns	97 / 85	ns	97 / 96(1)	ns
98 / 97	10%	98 / 96(2)	SIG	98 / 96(1)	SIG	98 / 89	ns
85 / 89	ns	85 / 86	ns	86 / 89	ns	98 / 86	ns
98 / 85	ns						

July Data	Wilcoxon Matched Pairs Test						
Years	Result	Years	Result	Years	Result	Years	Result
96 vs 85	ns	96 vs 87	10%	96 vs 89	10%	85 vs 87	ns
85 vs 89	ns	87 vs 89	ns				

October Data	Wilcoxon Matched Pairs Test						
Years	Result	Years	Result	Years	Result	Years	Result
96 vs 85	ns	96 vs 87	10%	96 vs 86	10%	96 vs 85	SIG
95 vs 87	10%	95 vs 86	SIG	95 vs 85	ns	87 vs 86	SIG
87 vs 85	SIG	86 vs 85	ns				

TABLE 4. *Statistical summary for the limpet size class data.*

April Data	Wilcoxon Matched Pairs Test						
Years	Result	Years	Result	Years	Result	Years	Result
96(2) / 89	SIG	96(2)/ 86	SIG	96(2) / 85	SIG	96(2)/96(1)	ns
96(1) /89	SIG	96(1) / 86	SIG	96(1) / 85	SIG	97 / 96(2)	SIG
97 / 89	ns	97 / 86	ns	97 / 85	ns	97 / 96(1)	SIG
98 / 97	ns	98 / 96(2)	SIG	98 / 96(1)	SIG	98 / 89	ns
85 / 89	ns	85 / 86	ns	86 / 89	SIG	98 / 86	SIG
98 / 85	ns						

July Data	Wilcoxon Matched Pairs Test						
Years	Result	Years	Result	Years	Result	Years	Result
96 vs 85	ns	96 vs 87	ns	96 vs 89	SIG	85 vs 87	ns
85 vs 89	ns	87 vs 89	SIG				

October Data	Wilcoxon Matched Pairs Test						
Years	Result	Years	Result	Years	Result	Years	Result
96 vs 85	ns	96 vs 87	SIG	96 vs 86	ns	96 vs 85	10%
95 vs 87	SIG	95 vs 86	SIG	95 vs 85	ns	87 vs 86	SIG
87 vs 85	SIG	86 vs 85	ns				

TABLE 5. *Statistical summary for the limpet size class data.*

April Data	z Test									
Years	Result		Years	Result		Years	Result		Years	Result
96(2) / 89	SIG		96(2)/ 86	SIG		96(2) / 85	SIG		96(2)/96(1)	ns
96(1) /89	SIG		96(1) / 86	SIG		96(1) / 85	SIG		97 / 96(2)	SIG
97 / 89	SIG		97 / 86	SIG		97 / 85	SIG		97 / 96(1)	SIG
98 / 97	SIG		98 / 96(2)	SIG		98 / 96(1)	SIG		98 / 89	SIG
85 / 89	SIG		85 / 86	SIG		86 / 89	SIG		98 / 86	SIG
98 / 85	ns									

July Data	z Test									
Years	Result		Years	Result		Years	Result		Years	Result
96 vs 85	SIG		96 vs 87	SIG		96 vs 89	SIG		85 vs 87	SIG
85 vs 89	SIG		87 vs 89	SIG						

October Data	z Test									
Years	Result		Years	Result		Years	Result		Years	Result
96 vs 85	ns		96 vs 87	SIG		96 vs 86	ns		96 vs 85	SIG
95 vs 87	SIG		95 vs 86	ns		95 vs 85	SIG		87 vs 86	SIG
87 vs 85	ns		86 vs 85	SIG						

DISCUSSION

Certain trends are common to all the data, pre and post *Sea Empress*. These are dealt with first to provide some background information on limpet breeding biology. Modifications to the trends in the light of the pollution will be discussed afterwards.

The total number of limpets at each height [Table 1]

Limpet numbers generally increase, up the shore, to reach a maximum at 3.75 metres above CD and then decrease to zero at 6.75 metres.

The decrease towards the top of the shore is due to problems of water loss, temperature stress and, possibly, lack of food and feeding time. Limpets graze selectively on green algae (both macro and microscopic), lichens and young fucoids. They often feed at night when the tide is out, or at any time when it is calm and the tide is in. Abiotic factors probably set the upper distribution limits (Branch, 1981).

Numbers decrease towards the bottom of the shore because of inter-specific competition from macroalgae and, to a lesser extent, barnacles on a sheltered rocky shore. Lower distribution limits are probably set by biotic factors (Branch, 1981).

It follows that optimum conditions for the common limpet exist in the middle of a sheltered rocky shore.

Size frequency [Table 2]

The 10.00 to 14.99mm size class is the best represented in the samples. To interpret these data,

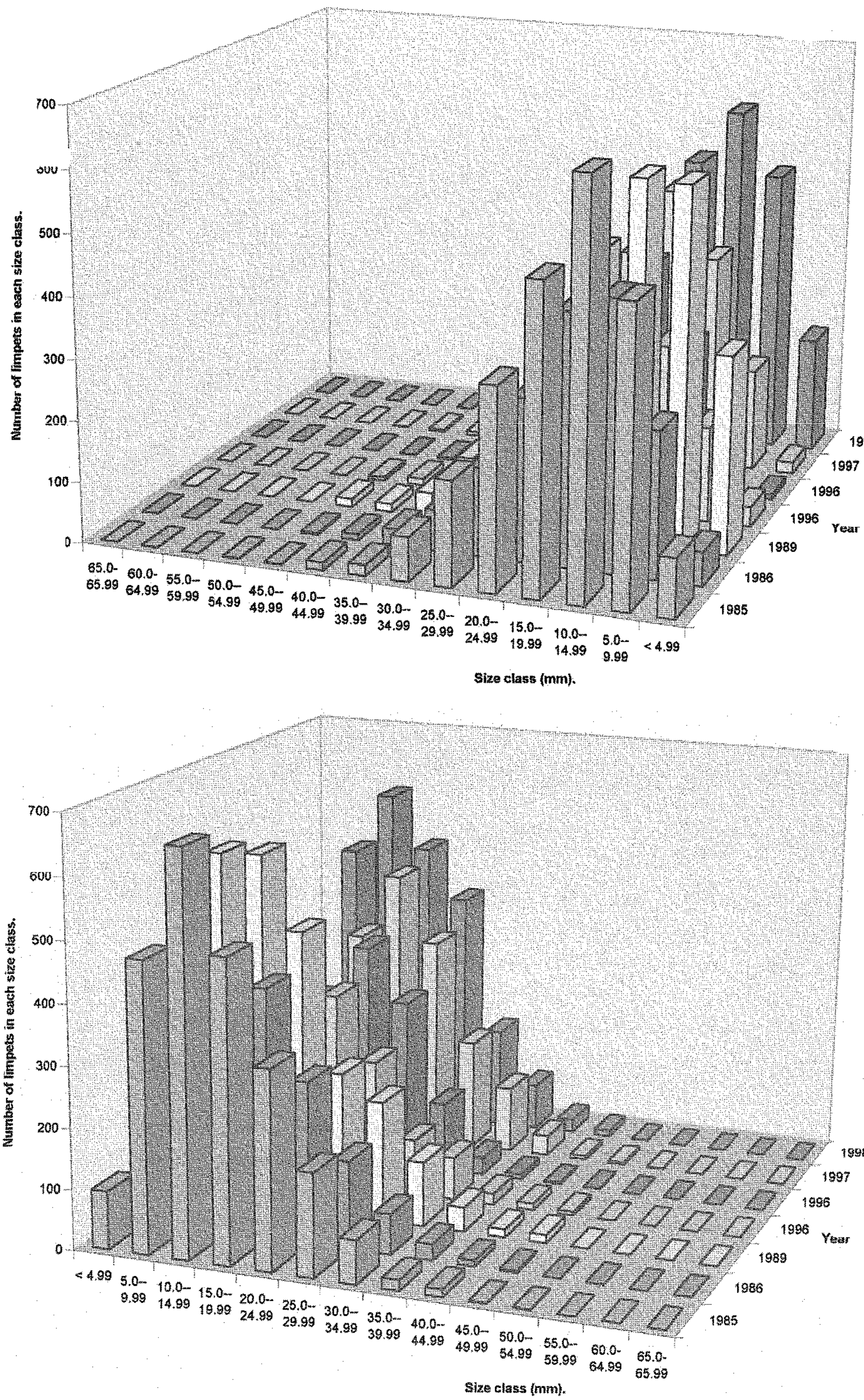

FIG. 2. Size frequency histograms for the limpets of Frenchman's Steps. April data from Table 2. The same data are plotted in each graph - but are displayed from different perspectives

for this particular shore, it is reasonable to assume that the smallest limpets are the youngest and the largest are the oldest[2]. Thus there are fewer larger, older, limpets because they die of old age.

There are very few small, young, limpets in most of the data sets. This could be for three reasons. Firstly, the very young limpets grow through the first few size classes relatively quickly. Secondly, students collecting the data are more likely to miss the very small limpets as they are harder to see. Thirdly, very small limpets tend to live in microhabitats such as pools and crevices which are undersampled.

Size range up the shore

Moving from the lower shore upwards, the modal group shifts to progressively larger size classes. In other words, on average, limpets are getting larger as height above CD increases. This trend is cited in the literature on more than one occasion (Das & Seshappa, 1948; Jones, 1948; Lewis, 1954 and summarised in Branch, 1981). To interpret this trend a look at the life cycle of the common limpet will be useful.

Limpets spawn (release their gametes into the sea water – fertilisation is external) from about October through to March with the peak period usually falling in November (Branch, 1981). Spawning is synchronised by increased water movement (associated with the autumnal gales) and falling sea temperatures (Lewis & Bowman, 1977). This produces a planktonic larval stage which remains in the zooplankton for a few weeks until a shell, approximately 0.2mm in diameter, is formed. The young limpet then settles on a rocky shore.

Most young limpets settle on the lower shore simply because the water that they are settling from is there most of the time. Even if young limpets settled evenly all over the shore, most would survive on the lower shore because they are extremely vulnerable to desiccation when young because of the thinness of their shell. For these two reasons there are more young limpets on the lower shore. Suitable micro-habitats, crevices and rock pools for example, will allow survival of young limpets in the upper parts of the shore (Lewis & Bowman, 1975). On the shore in question, there are many crevices and a few rock pools, to enable upper shore survival of the young, but not enough to over ride the general trend.

The information outlined above is well documented in the literature (Branch, 1981) but the next part of the explanation is only a plausible hypothesis and should be treated accordingly. It is suggested that the average size of limpets increases with increasing height above CD because they migrate up the shore as they get older. The stimulus, for what at first might seem to be maladaptive behaviour, is competition for space which is intense at the bottom of the shore. (Lewis, 1954.)

Another well-documented facet of limpet biology is that the animals have a "home scar" (Branch, 1981.) This is a place on the rocks to which a limpet will return after each feeding excursion. Where the rocks are uneven and hard, as they are around Dale Fort, the limpet will secrete shell to compliment the contours of its home (i.e. grow its shell to fit the rock). In these cases, homing will by necessity be rigid. If the limpet did not return home its shell would not fit the rock and it would be vulnerable to water loss and/or predation. If the rocks are flat, then rigid homing does not seem to be as important, some animals at Watchet in the Bristol Channel are known to have up to three "homes" and will alternate between them regularly. (Crothers, pers. comm., 1990.)

This "homing" fact seems to be at variance with the "migration" hypothesis. One explanation that would seem to satisfy both requirements is that limpets may show fidelity to a particular home scar until they become too large for it. If the home is surrounded by barnacles, which most certainly are on Frenchman's Steps, it would seem reasonable to suppose that one day the limpet will grow too large for the available space. When this happens perhaps the stimulus of lack of space operates and the limpet migrates up the rocks to a new home?

[2] limpets of the genus *Patella* grow throughout their lives

THE EFFECTS OF THE *SEA EMPRESS* OIL ON THE STUDY POPULATION

Data collected in April 1996

Tables 1 and 2 show the post *Sea Empress* 1996 limpet totals to be considerably lower than in the earlier years, especially on the lower half of the shore and in the smaller size classes. The simple conclusion is that the oil spill had killed those limpets (mortality had been observed in March, p.529). Statistical analysis of the data, summarised in Tables 3-5, suggest that the differences, for the most part, are significant. Differences between the two 1996 data sets were not significant and, indeed, neither were the differences between any of the pre *Sea Empress* data sets.

This is interesting on a number of levels. The data presented in this paper were collected by Dale Fort students. The lack of significance in the differences between the two 1996 data sets, and between all the pre-1996 sets, attests favourably to the reliability of the information. It also suggests that variation in the population numbers and size structure from one "normal" year to another may not be large enough at this site (but see Dicks, 1987 p.113) to obscure all effects of the pollution.

Having said that, it must be noted that there *are* variations in limpet numbers between years. The data for April 1989 (Table 1) show unusually large limpet numbers on the lower half of the shore. The increase was mainly in the smaller size classes (Table 2) which seems to suggest that there had been particularly good settlement in 1988 and 1989.

From Table 2, it is apparent that the modal class of the pre-*Sea Empress* data is in the 10.0-14.99mm size class. In 1996, the modal class had shifted to the 15.0-19.99mm size class. Two factors might contribute to a shift in the modal class to the right (larger size classes). One, if the total number of limpets stays approximately the same, then the observed shift could be produced if the limpets are increasing in size. Two, the same shift could be produced if smaller limpets are decreasing in number. As there were markedly fewer limpets present in 1996, and that there was no evidence at that stage to suggest that the limpets had really increased in size, it would seem that the pollution had affected the smaller, younger, limpets disproportionately. This result is in line with expectations.

The Wilcoxon Matched Pair analysis (Table 4), which compares size class with size class, suggests that the pollution effects are significant (1996 data compared with earlier years). The two 1996 data sets and most of the pre SE data sets were not significantly different from each other. The exception to the latter trend is the 1986/1989 comparison which did show a significant difference but this is most likely due to the abnormally high settlement mentioned above.

The 'z' tests carried out on the limpet size class data (Table 5), confirmed that the shift in the modal class was significant for all pre- and post- *Sea Empress* comparisons. The two 1996 sets of data were not significantly different, once again, but this time the average size of limpets on the shore as a whole varied significantly from one "normal" year to another. In all cases, however, the magnitude of the difference was greater in post- versus pre- comparisons than in pre- versus pre-.

Summary of the April 1996 observations. The *Sea Empress* pollution has reduced the total number of limpets on the shore and has affected the smaller, younger limpets most.

Data collected in July 1996

The patterns present in the July data are broadly similar to those described for April. However there are a number of interesting differences. Looking at the number of limpets at each height up the shore (Table 1), it will be noted that the number of limpets at 2.25m above CD is no longer so obviously below expected figure for this level. This might be interpreted as the first signs of a recovery. If this is the case, it would suggest that there was some limpet recruitment to the "visible" population, later in the year than is usual. Information from all over Pembrokeshire, summarised in the Dyfed Wildlife Bulletin for August 1996, "Marine Matters" in the Dorset Wildlife Trust September newsletter and local observations by Dale Fort staff, suggested that, due to the abnormally cold spring weather in 1996, most marine organisms were at least a month behind their "normal" schedules that year. Therefore it is possible that late limpet recruitment could have contributed to the observed result. But the young recruits, living in crevices and/or pools, would have been extremely difficult to see in post oil-spill conditions therefore not show up in the data sets until later in the year.

Summary of the July 1996 observations. The trends are similar to those described for April but there is a hint of the start of a recovery phase.

Data collected in October 1996

Looking at the data for number of limpets at each height (see Table 1), there is no longer any dramatic difference between 1996 and the earlier years. Indeed, the statistical analyses (Tables 3-5) reveal more in the way of normal variation than in pre and post variation. Both the Wilcoxon and 'z' tests show a blurring of the distinct differences that were present in April. Having said that, the shift in the modal class from the pre-*Sea Empress* 10.0-14.99mm norm to 15.0-19.99mm is still apparent. Since numbers have apparently recovered to "normal" levels it would appear that the shift in the modal class may now be due to an actual increase in limpet size, perhaps because of an increased food supply per limpet.

A definite pollution effect was visible in the April 1996 data but this was decreasing in July and, by October, there had been a recovery to near normal population levels. Having said that, there was no obvious cohort of individuals within the population that could be said to represent this recovery age group.

One plausible explanation of the observed trend is that the young present in, or shortly after, April may have survived in cleaner micro-habitats on the shore. (There are a number of deep, narrow crevices on the study shore. The author's impression is that these are ideal, damp, juvenile limpet refuges, too small for appreciable amounts of oil to have entered.) Limpets living in these micro-habitats might not only have been less susceptible to pollution but also were difficult (impossible) to see and, therefore, record.

From April 1996 onwards, food supply per individual limpet must have been much greater than in normal years because of the reduced inter- and intra-specific competition apparent as the shore displayed the green flush typical of a post oil-pollution, first recovery phase. Limpet growth rates are very sensitive to food supply (Jones & Baxter, 1986) so the 1996 cohort could have grown through the smaller size classes rapidly. Jones & Baxter (1986) suggest that *Patella vulgata* grows fastest in its first year and may reach 15mm. In the October 1996 data, the number of individuals in the 10.0-14.99mm and 15.0-19.99mm size classes is greater than in April or July, which suggests that that was where the late settling, post-pollution survivors, made their contribution to the population.

Another way that limpet numbers could have recovered, without input from reproductive effort, is by way of horizontal migration (R. Crump, pers. comm. 1996). No data exist, for this shore, to verify the significance of this behaviour but it is an interesting further possibility. However, since the shore was oiled fairly evenly along its length, it is unlikely that horizontal migrations, in or out of the study area, would have conferred any advantage to the limpets in question.

Summary of the October 1996 observations. No discernible pre- and post- *Sea Empress* Incident differences in the number of limpets remained. The shift in modal class was still visible but now the explanation inferred an actual increase in limpet size as a result of increased availability of food.

Data collected in April 1997

by a final-year group of under-graduates from the University of Leuven, Belgium

Limpet numbers were approaching "normal" levels for April (Table 1). This adds credence to the suggestion (above) that there had been at least a partial recovery by October 1996. However, the number of limpets at the bottom site, 2.25m above CD, remained low. In fact, this was nothing whatsoever to do with the *Sea Empress*. In October 1996, there were hurricane force winds in the Milford Haven waterway, which changed the configuration of many of the local beaches by anything up to two metres in height! The bottom site at Frenchman's steps was altered in that there are now more pebbles covering it than before. The available suitable habitat for limpets, bare rock, had decreased. This reinforces the point that local knowledge of the site and pre-pollution data sets are an invaluable asset when attempting to assess the effect of pollution on natural communities.

Although the numbers of limpets were approaching normal, there were still observable differences in the population structure. The modal size class was still in the 15.0-19.99mm bracket. This seemed to reinforce the suggestion that the abundant food supply, both in total and per limpet, had allowed a significant increase in the average size of the limpets on that shore. Some of the raw data for the 'z' test calculations is shown below in Table 6 for ease of reference. Note that the mean size of the limpets for the shore as a whole has been larger since the spill and was larger in 1997, and significantly so, than ever before.

Summary of the April 1997 observations. Numbers of limpets at each height had returned to near normal, one year after the spill, but the structure of the population was still different. The modal size class had shifted one category to the right and the mean size of limpets (on the shore as a whole) was significantly bigger than ever before.

Data collected in April 1998

by another final-year group of under-graduates from the University of Leuven, Belgium

For the first time since the pollution event, the modal size class had returned to its normal position in the 10-14.99mm bracket (Table 2). This suggested recovery of the population structure as well as density. The mean size of the limpets (Table 6) had dropped for the first time since 1996. The data in Table 1 suggested that the return to the normality was due to a good settlement of young from the plankton and their subsequent recruitment to the population.

Summary of the April 1998 Observations. Two years after the *Sea Empress* incident, the study population of limpets on Frenchman's Steps, Dale has returned to what might be considered normal for that shore.

TABLE 6: *Summary of the 'z' test calculations on the April data sets.* $\bar{x}$ = *sample mean size of limpets (mm), s the sample standard deviation,* s^2 *the sample variance.*

April Data	YEAR						
Statistic	**1998**	**1997**	**1996(2)**	**1996(1)**	**1989**	**1986**	**1985**
n	2441	1725	1165	1224	2586	1660	2327
$\bar{x}$	**15.45**	**18.95**	**18.37**	**17.86**	**14.69**	**17.05**	**15.65**
s^2	64.25	58.59	40.70	65.57	82.75	62.01	58.72
s	8.02	7.65	6.38	8.10	9.10	7.87	7.66

Final Note (June 1998)

From the growth rate figures for *Patella vulgata* in the literature (e.g., Jones & Baxter, 1986), it seems reasonable to suggest that recovery of the population density was possible within one year, given an adequate settlement.

Discussions with Dr Bill Ballantine, in the summer of 1997, suggested another possibility. His work on *P. vulgata* (spanning forty years but still unpublished at the time of writing) on shores around Dale Fort Field Centre suggested that the growth rates of very young limpets may be slower than previously thought. He considers that young limpets may remain in suitable micro-habitats for a year or more before entering the "visible" (hence countable) population on the shore. If this is, indeed, the case then the observed recovery of limpet numbers may have been due to 'recruitment' from small individuals, already present on the shore, that survived in pollution-free refuges within the rock structure. Once out in the open, the abundant food supply could have produced the growth needed to put then into the 15+mm size class by October.

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