# LONG-TERM CHEMICAL AND BIOLOGICAL EFFECTS OF A PERSISTENT OIL SPILL FOLLOWING THE GROUNDING OF THE *GENERAL M. C. MEIGS*

*Robert C. Clark, Jr., and John S. Finley*
*National Marine Fisheries Service*
*National Oceanic and Atmospheric Administration*
*Seattle, Washington*

*Benjamin G. Patten*
*National Marine Fisheries Service*
*Mukilteo, Washington*

*and*

*Edward E. DeNike*
*Washington State Department of Ecology*
*Olympia, Washington*

## ABSTRACT

*Petroleum hydrocarbon uptake patterns and observations of plant and animal populations of an intertidal community exposed continually since January 1972 to small quantities of a Navy Special Fuel Oil residue from the grounded unmanned troopship **General M. C. Meigs** were obtained by an interagency team of oceanographers, biologists, chemists, and engineers. Although the tar-ball-like character of the released oil served to limit its coverage, specific members of the intertidal community showed effects of the persistence of the spill. This report describes the long-term observations and analyses made since the grounding of the 622-foot military transport on a rich and productive intertidal regime.*

## INTRODUCTION

The environment at Portage Head on the northwest coast of Washington (figure 1) was changed by the grounding of the *General M. C. Meigs* (AP-116) on January 9, 1972. Oil from the ruptured fuel tanks of the 190-meter (662-foot) unmanned troopship has been continually released into an open ocean intertidal community since the grounding.

When the *General M. C. Meigs* ran aground, the hull broke into two parts forming an extensive breakwater against the incoming waves. Later the fantail separated from the stern section. In the course of two and one-half years, the stern section has been slowly torn apart by the wave action until just a portion of it remains above the water surface. The bow section has remained in its initial position with little loss of superstructure.

Oil from the ruptured fuel tanks moved over the shallow rock shelf inshore from the hulk as a large single oil spill during the first two days following the grounding. As more tanks were breached, oil in the form of discrete globules was released, and these floated into Wreck Cove where they became incorporated with the coarse sand beach. Effects of the persistent oil contamination have been reported for the initial 10-month period covering immediate and short-term damage to the biota of the rock shelf inshore from the *General M. C. Meigs* [1].

Petroleum hydrocarbon uptake by the biota has been investigated and studies of animal and plant populations have been undertaken by an interagency research team from the Northwest Fisheries Center of the National Marine Fisheries Service (National Oceanic and Atmospheric Administration), the Technical Services Section of the Washington Department of Ecology, and the Environmental Protection Agency (Region X) to determine the long-term effects of the oil spill.

Recovery of the disturbed area, as studied from January 1973 to August 1974, is reported in this paper. Qualitative and quantitative differences during the period of study show the extent of recovery of the area from oil contamination.

### Petroleum hydrocarbon uptake

**Methods.** Selected species of plants and animals that had been exposed to oil contamination from the *General M. C. Meigs* were compared with unexposed control specimens of the same species. Sample collections were made during the low tide periods in 1972 (February 9, March 15, April 18, May 15, June 12, August 9, and October 20); in 1973 (January 17, February 12, March 9, June 19, July 27, and October 25); and in 1974 (February 4 and August 19). All samples were chilled for transportation to Seattle and frozen within 16 hours. Details of the basic collection, preservation, preparation, and analysis of intertidal biological specimens to determine uptake of pollutant hydrocarbons have previously been described [2,3].

The algae (*Fucus gardneri, Calliarthron schmittii,* and *Bossiella* sp.) and the false eel grass (*Phyllospadix scouleri*) were extracted whole after removal of epiphytic algae, endemic organisms, and excess surface water. Sea urchins (*Strongylocentrotus purpuratus*) were crushed and extracted, and large barnacles (*Balanus cariosus*) were extracted whole and crushed between the two extraction stages [2]. Crabs (*Hemigrapsus nudus*) were cut up while frozen, and mussels (*Mytilus californianus*) were shucked while partly thawed; both were homogenized between extractions.

The *n*-paraffin hydrocarbons were quantified by gas chromatography, and the concentrations were recalculated on a parts-per-billion

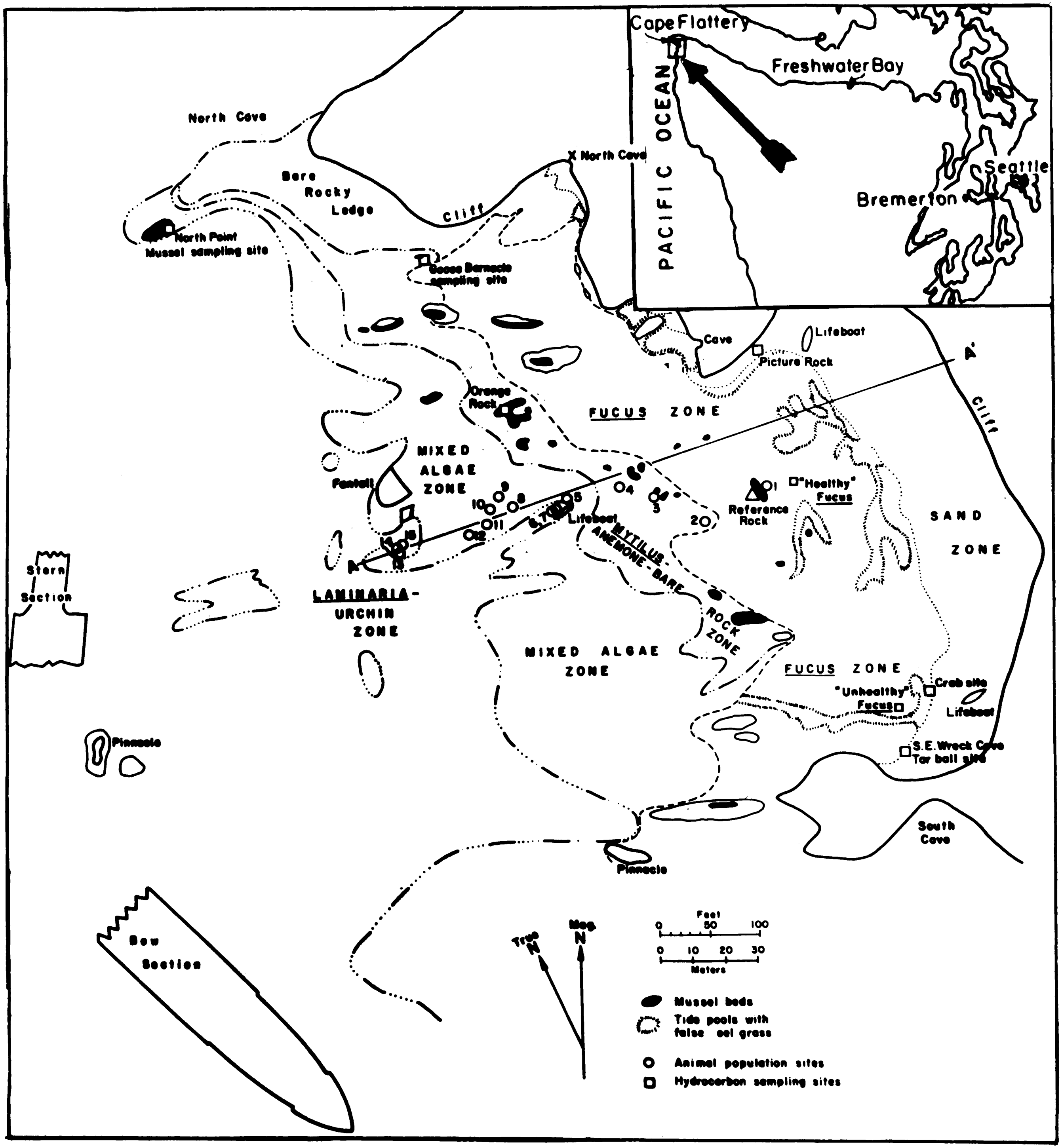


Figure 1. Detailed base map of Wreck Cove showing the hydrocarbon uptake sampling sites and animal population study sites.

(PPB), dry extracted weight basis, which we define as the concentration of each individual *n*-paraffin ($10^{-9}$) divided by the sum of the weights (*g*) of the dry residue remaining after removal of the organic material plus the methanol/benzene-free solvent extractables [2]. This combined weight is simply the original weight of the sample less the weight of the water and water-soluble components of the organisms. This resulting PPB value is plotted on semi-logarithmic paper against the number of carbon atoms per molecule, a method which allows easy comparison of several *n*-paraffin hydrocarbon patterns on a single graph regardless of original sample size or dilution.

**Results: plants and algae.** The false eel grass (*Phyllospadix scouleri*) in Wreck Cove (figure 1) was heavily oiled immediately after the grounding. One sample of the grass collected one month after the grounding retained as much as 41% of its dry weight as oil (based on normal paraffin hydrocarbon analysis), which means that this species served as an effective natural oil sorbent. Most of the intertidal algae have a mucous coating which minimizes significant oil retention.

A *Fucus gardneri* sample collected in Southeast Wreck Cove near the crab site (figure 1) 3 months after the grounding was labeled "unhealthy" because of its dark and flaccid appearance although it had no observable oil coating or petroleum odor. A brighter, greener crisp sample, classified "healthy," was collected near sampling site 1 [1]. Previous analysis of this unhealthy sample revealed concentrated *n*-paraffin hydrocarbons from the spilled oil of the order to 8 PPM (dry weight: $n$-$C_{14-37}$). After one year of exposure, *Fucus* collected at the same sites had a residual paraffin pattern similar to that of the pollutant and an *n*-paraffin residual content of 160 PPM.

Other criteria of pollutant uptake such as low $n$-$C_{17}$ to pristane ratio, low major hydrocarbon content (percent $n$-$C_{15}$, the principal biogenic *n*-paraffin), low $n$-$C_{16}$ ratio, low carbon preference index ($CPI_{14-20}$), and a low unresolved peak envelope at $C_{17}$ as compared with higher values for the healthy sample also indicate considerable contamination of the unhealthy sample (January 1973; table 1).

Six months later (June 1973), similar analyses revealed only negligible differences in biogenic baseline hydrocarbon levels between *Fucus* samples collected at the two previous sites in Wreck Cove. These two summer samples had similar hydrocarbon patterns, content, and calculated parameters (table 1) to an unexposed *Fucus* sample collected at Waatch Point a year earlier. Our investigations did not provide sufficient information to allow us to state whether the results found a year and one-half after the incident were due to loss of the pollutant or to replacement of the contaminated *Fucus* with new uncontaminated growth. The algae at the unhealthy site two and one-half years later (August 1974) appear visually indistinguishable from the healthy specimens.

One coralline alga (*Calliarthron schmittii*) was examined from Wreck Cove one month after the grounding. The only other coralline alga available as an uncontaminated control was *Bossiella* sp. collected at Freshwater Bay (located west of Port Angeles, Washington; part of the NMFS Puget Sound Hydrocarbon Baseline Studies sampling system). This alga displayed the same basic odd-carbon predominance as the *Calliarthron* sp. (figure 2) and a $CPI_{14-20}$ of 110 compared with 9.9 for *Calliarthron* sp. and a $CPI_{20-36}$ of 11 for *Bossiella* sp. compared with 5.7 for *Calliarthron* sp. (table 1). These facts suggest that within the first month following the incident, this calcified alga did not appear to incorporate measurable concentrations of the pollutant.

**Sea urchins.** In the area immediately inshore from the hulk, purple sea urchins displayed obvious signs of change by the loss of spines [1]. Specimens collected three months after the incident in April 1972 had greater *n*-paraffin content than specimens collected a month later (table 1; 2.4 PPM compared with 0.25 PPM, dry weight; 1-3 whole frozen organisms). The *n*-paraffin patterns (figure 3A) show a pollutant-like pattern for the April specimens and an intermediate pattern for May.

The *n*-paraffin hydrocarbon pattern of the urchins collected at the Mukkaw Bay control site is assumed to represent the biogenic or natural hydrocarbon baseline of the urchins; the *n*-paraffin pattern of the exposed urchins from Wreck Cove represents the biogenic baseline plus the pollutant uptake. If one subtracts the *n*-paraffin pattern of the control from that of the exposed, the difference constitutes the "residual" *n*-paraffin hydrocarbon pattern of the fuel oil. The residual patterns for the urchins (figure 3B; peaks at 17, 28, 30-31, 35 and troughs at 19, 29, 33) confirm the fact that a positive residual content exists and that the residual hydrocarbon pattern of the urchins is similar to the plotted pattern of a Navy Special Fuel Oil residue.

**Crabs.** The purple shore crabs collected two months after the spill displayed oil residue patterns [1]. Samples collected five months later (October 1972) have been analyzed (figure 4A) and compared with crabs taken the previous and following November at Freshwater Bay, an uncontaminated area. The residual paraffin pattern obtained by subtracting the mean of the individual *n*-paraffin hydrocarbons from the two control samples (November) shows (figure 4B) a pattern similar to a weathered oil sample collected in the same areas as the crabs (peaks at 16, 21, 25, 28, 30-31 and troughs at 15, 17, 22, 26, 29). While the residual patterns are similar, the levels of pollutant uptake were roughly twice the biogenic baseline level and about one-fifteenth that found five months earlier.

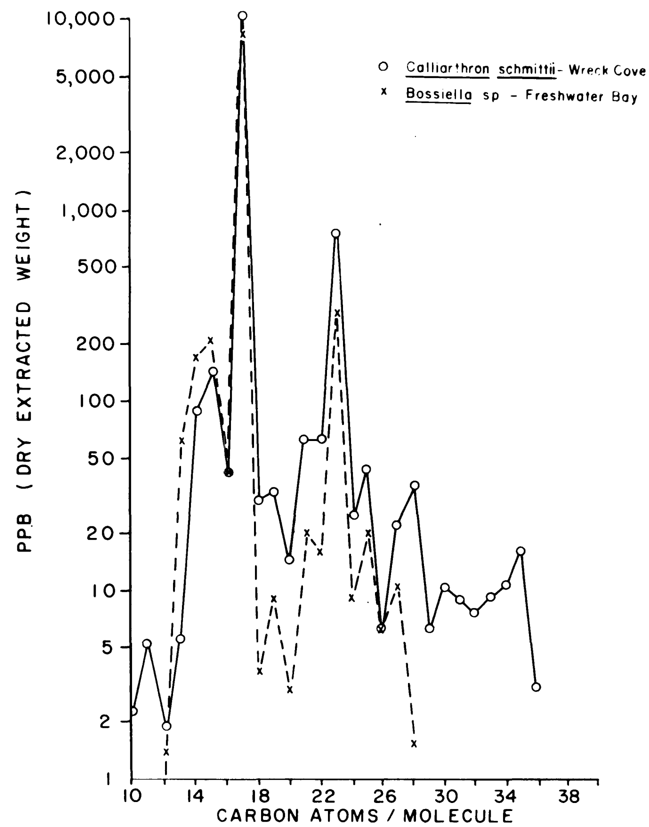


Figure 2. Paraffin hydrocarbon patterns for coralline algae: *Calliarthron schmittii* from Wreck Cove compared with *Bossiella* sp. from Freshwater Bay.

## Animal population observations

**Methods.** Species present and numerical density of selected abundant animals were determined on January 20, 1973, July 27, 1973, and August 20, 1974, at times of low tides. Procedures have been reported [1] but are briefly reviewed here.

Observations were made at 15 stations (figure 1)—station 1 the inshoremost and 15 the offshoremost. Stations were marked by a flagged nail driven into the rock. Species of animals were determined by searches within about a 5-m radius of the station marker. Searches were of varying durations and usually abbreviated because of time limitations from incoming tides. The level of the tide was too high in January 1973 for observations beyond station 12. Numerical density of animals was determined by positioning a 30-cm square grid with the nail station marker and a compass. By this method, count observations were made near identical areas for this study and the preceding one [1]. Counts within the grids were made within a 10-cm square except at station 12A where all animals in the grid were enumerated. Counts consisted of live animals and also dead animals as in the cases of the barnacles (*Chthamalus dalli* and *Balanus cariosus*) and the coastal mussel (*Mytilus californianus*).

**Evidence of changes.** Species of animals recorded and numerical biomass of selected animals varied; however, this is considered to approximate natural fluctuations. Species observed in 1972 [1] were recorded in the present study for 1973-1974 (table 2), and no new common species were identified except for the crab (*Cancer oregonensis*) found in recesses in rock. Zonation of species within the tidal area was essentially the same between the two studies.

**Table 1. Normal paraffin hydrocarbon data analysis of plants, animals, and fuel oil residues on a dry-weight basis from the General M. C. Meigs***

| Sample analyzed / Location collected | Month | Solvent extractables (PPM x $10^3$) | Total $n$-paraffin hydrocarbons ($C_{14-37}$ - PPM) | $n-C_{17}$/pristane ratio | Major $n$-paraffin | Percent major $n$-parraffin | $n-C_{16}$ ratio | $CPI_{14-20}$ | $CPI_{20-36}$ | Unresolved peak envelope $C_{17}$/background |
|---|---|---|---|---|---|---|---|---|---|---|
| FALSE EEL GRASS (*Phyllospadix scouleri*) | | | | | | | | | | |
| Wreck Cove | Feb 1972 | 350 | 2000 | 0.9 | 31 | 10% | 32 | 1.6 | 1.0 | 2.3 |
| Waatch Point | April 1972 | 63 | 570 | 1400 | 17 | 50% | 12 | 8.5 | 2.7 | 310 |
| ALGAE | | | | | | | | | | |
| *Fucus gardneri* | | | | | | | | | | |
| Waatch Point | June 1972 | 71 | 33 | >170 | 15 | 96% | 330 | 260 | 0.7 | 9.2 |
| Wreck Cove unhealthy site | Jan 1973 | 76 | 180 | 1.3 | 15 | 47% | 24 | 5.3 | 1.0 | 2.4 |
| Wreck Cove, healthy site | Jan 1973 | 68 | 18 | 54 | 15 | 96% | 314 | 248 | 1.3 | 6.4 |
| Wreck Cove, unhealthy site | June 1973 | 87 | 30 | >350 | 15 | 97% | 310 | 260 | 1.4 | 21 |
| Wreck Cove, healthy site | June 1973 | 80 | 29 | >370 | 15 | 96% | 200 | 180 | 1.0 | 16 |
| *Calliarthron schmittii* | | | | | | | | | | |
| Wreck Cove–Orange Rock | Feb 1972 | 4.2 | 13 | >1000 | 17 | 88% | 300 | 99 | 5.7 | 750 |
| Bossiella sp. | | | | | | | | | | |
| Freshwater Bay | May 1971 | 3.5 | 9.2 | >2000 | 17 | 91% | 210 | 110 | 11 | 190 |
| SEA URCHINS (*Strongylocentrotus purpuratus*) | | | | | | | | | | |
| Wreck Cove | April 1972 | 24 | 2.4 | 0.6 | 17 | 14% | 56 | 2.8 | 1.0 | 5.2 |
| Wreck Cove | May 1972 | 15 | 0.25 | 0.7 | 17 | 23% | 66 | 4.5 | 0.8 | 6.3 |
| Mukkaw Bay | May 1972 | 21 | 0.12 | 1.5 | 15 | 48% | 690 | 27 | 1.4 | 14 |
| CRABS (*Hemigrapsus nudus*) | | | | | | | | | | |
| S.E. Wreck Cove | Oct 1972 | 36 | 1.2 | 33 | 17 | 16% | 53 | 4.3 | 1.2 | 1.9 |
| Freshwater Bay | Nov 1971 | 51 | 0.37 | 16 | 17 | 27% | 260 | 12 | 4.2 | 4.4 |
| Freshwater Bay | Nov 1972 | 29 | 0.75 | 6.2 | 17 | 37% | 100 | 27 | 1.8 | 3.8 |
| NAVY SPECIAL FUEL OIL RESIDUES† | | | | | | | | | | |
| Picture Rock | April 1972 | 600 | 15,000 | 2.3 | 18 | 8% | 17 | 0.9 | 1.0 | 2.5 |
| Picture Rock | June 1973 | 530 | 12,000 | 1.6 | 30 | 12% | 50 | 1.2 | 0.9 | 2.4 |
| Picture Rock | Feb 1974 | 490 | 11,000 | 0.3 | 31 | 9% | 140 | 1.9 | 1.0 | 2.2 |
| "Old" globule on Rock | Oct 1972 | 660 | 2,500 | 0.7 | 30 | 11% | 28 | 0.7 | 1.2 | 1.5 |
| "Old" globule on Beach | Feb 1974 | 89 | 160 | – | 30 | 14% | – | – | 0.9 | 1.3 |
| Sand sample–Picture Rock | Aug 1972 | 0.53 | 0.23 | 2.2 | 30 | 21% | 130 | 2.6 | 0.8 | 2.7 |
| Foam sample–high tide | Oct 1973 | 360 | 260 | 0.2 | 25 | 10% | 120 | 2.0 | 1.2 | 2.8 |
| "Fresh" globule–North Pt. | June 1972 | 950 | 10,000 | 1.7 | 20 | 7% | 16 | 1.0 | 1.1 | 2.7 |
| "Fresh" globule–Wreck C. | June 1972 | 670 | 8,200 | 1.0 | 30 | 9% | 18 | 0.9 | 0.9 | 2.0 |
| "Fresh" globule–Wreck C. | June 1973 | 370 | 8,600 | 0.5 | 30 | 8% | 20 | 1.0 | 1.0 | 1.8 |
| "Fresh" globule–Wreck C. | Feb 1974 | 480 | 3,900 | 0.6 | 31 | 8% | 28 | 1.0 | 1.1 | 2.0 |
| Whole oil–composite sample | 1971 | 950 | 40,000 | 1.6 | 18 | 10% | 10 | 1.0 | 1.0 | 3.2 |

*All data rounded to two significant figures
†Pentane-soluble material

Count numbers and ratios between live and dead animals usually were similar, but sometimes there were large variations (table 3) as in the 1972 study [1]. The greatest differences were in the *Chthamalus* sp. barnacles at station 5 between the present and the 1972 study. The trend in this example, as with most other stations, was for fewer individuals in the latter study.

Abundance of a colony of anemones (*Anthopleura elegantissima*) at station 4 decreased as determined by the estimated percent of substrate they covered within the 30-$cm^2$ study quadrant. From March to June 1972 the colony covered 30% of the available substrate. This decreased to about 10% from October 1972 to July 1973. Percentage of cover was less than 5% on August 1974.

All the urchins (*Strongylocentrotus purpuratus*) appeared healthy in August 1974. A few individuals had aspinous areas on their sides during the January and July 1973 surveys.

## Plant population observations

During the summer of 1973, the brown alga (*Hedophyllum sessile*) outstripped other algae species to become the predominant algae in the middle intertidal zone of Wreck Cove. By the summer of 1974, however, other algae species, such as *Halosaccion, Egregia, Desmarestia, Gigartina, Rhodoglossum, Iridaea, Codium* and *Ulva,* began to appear in a normal distribution pattern.

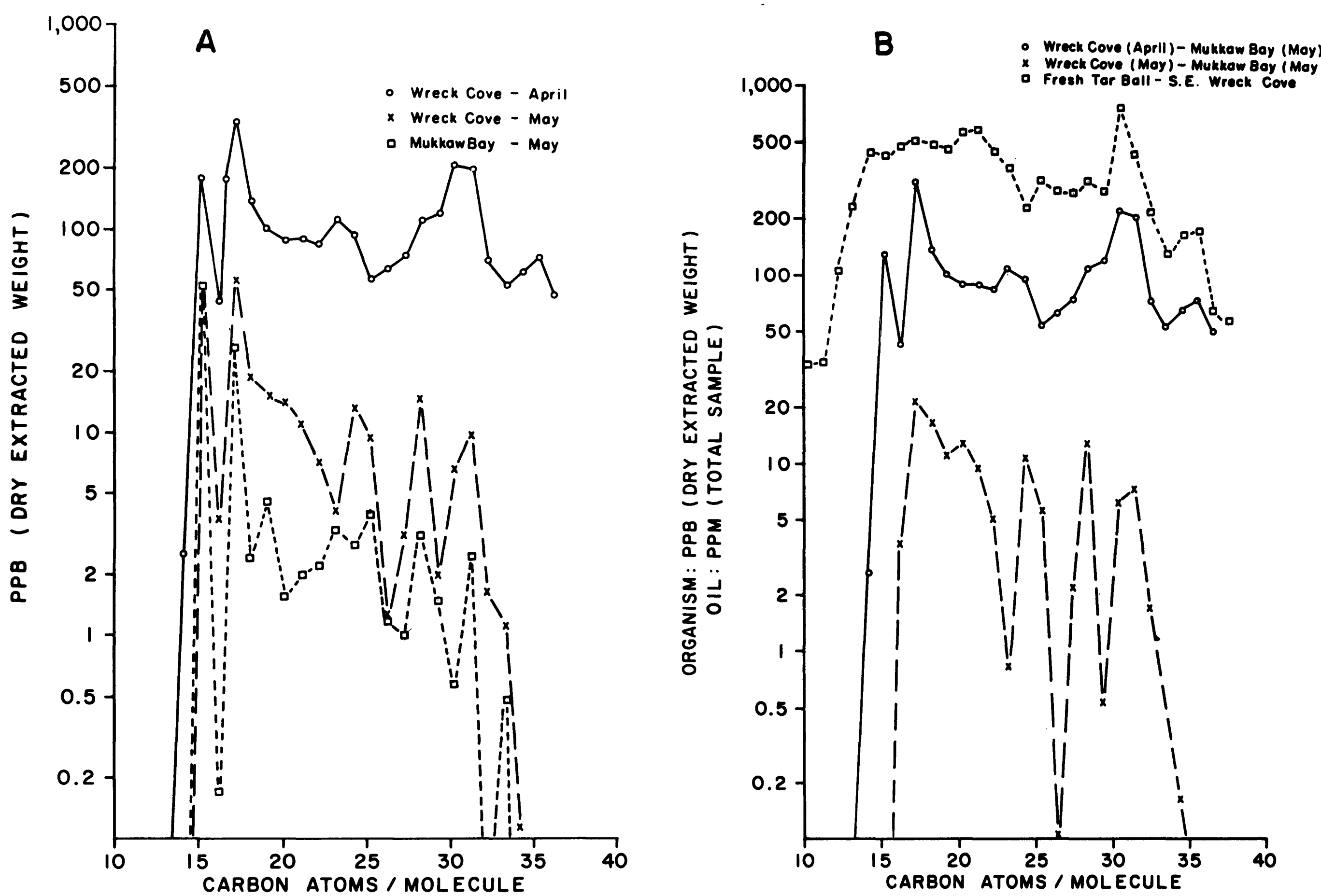


Figure 3. Paraffin hydrocarbon patterns for sea urchins (*Strongylocentrotus purpuratus*) exposed to Navy Special Fuel Oil residues from the *General M.C. Meigs*. (A) Wreck Cove samples (April and May 1972) compared with a control sample from Mukkaw Bay (May 1972). (B) The residual hydrocarbon pattern (Wreck Cove minus Mukkaw Bay) compared with a Navy Special Fuel Oil residual pattern.

Damage to the fronds of *Laminaria andersonii* in the lower intertidal zone, which was observed during the summer of 1972, was still apparent two years later. It is possible that this alga still has not recovered from the initial oil spill.

The red algae (*Prionitis lanceolata*) and the corallines (*Bossiella* sp. and *Corallina* sp.), which exhibited partially bleached thalli throughout the year following the spill, no longer displayed this phenomenon.

## Weathering of the fuel oil

**Methods.** The globules (tar balls, usually 4-6 cm in diameter and several cm thick) and scrapings from rocks were stored chilled in aluminum foil and frozen on return to Seattle. The samples were extracted with three rinses of pentane (1-50 v/w) and 1 to 2 minute exposures in an ultrasonic bath. The pentane-solubles were then chromatographed over silica gel and alumina in the same manner as the biological samples [1], and the insoluble residue was dried and examined microscopically.

**Picture Rock.** In the first two days following the grounding, the near-hurricane conditions caused considerable amounts of oil to be deposited on a rock (Picture Rock, figure 1) located about 2.8 meters above mean lower low water in the northwest extreme corner of Wreck Cove. A series of color photographs were made of this boulder (approximately 1.5 meters in diameter) during the fifteen surveys to the wreck site over a period of 31 months. Since the oil was well above the usual tide line and only occasionally exposed to the splash from winter storms, oil residues have remained in the cracks and crevasses (1-10 mm depth) of the rock.

Chemical analysis of the *n*-paraffin hydrocarbon components (figure 5) have shown the usual loss of low molecular weight hydrocarbons [4], but the loss we observed was slow ($n$-$C_{17}$ of 880 PPM after 3 months, 340 PPM after 17 months, and 130 PPM after 25 months)—a finding similar to that of Blumer et al. [5] for a weathered oil sample on a warm and dry rock on Martha's Vineyard studied for 15 months.

**Oil globules from the tidal zone.** When oil residues were exposed to wave action and biological degradation some changes were seen (figure 6). An "old" tar globule was collected from a rock underneath the *Fucus* algal canopy in Southeast Wreck Cove nine months after the incident. The globule appeared flat, dull brownish-black, and imbedded with pebbles, shell fragments, and plant fibers. The globule had no strong petroleum odor until a portion of its exterior was cut away. The hydrocarbon pattern shows some loss of lower molecular weight paraffins, but even at this date, if the sample was assumed to have been deposited in the initial large spill when this ledge area was coated with an oily layer, there is remarkably little degradation.

On the other hand an "old" tar globule found on the coarse sand beach in Southeast Wreck Cove in February 1974 had lost significant *n*-paraffins and contained large amounts of sand. It is probable that physical and bacteriological action in a dynamic beach area accounted for at least some of the loss of the paraffins. No pristane nor phytane were detected in the extract, but neither were there any paraffins below $C_{20}$ with concentrations greater than 1 PPM total globule weight. By weight, over 91% of this old tar globule consisted of pebbles, rocks, sand, shell fragments, and plant fibers glued together by the oil into a brittle matrix emitting only a slight petroleum odor.

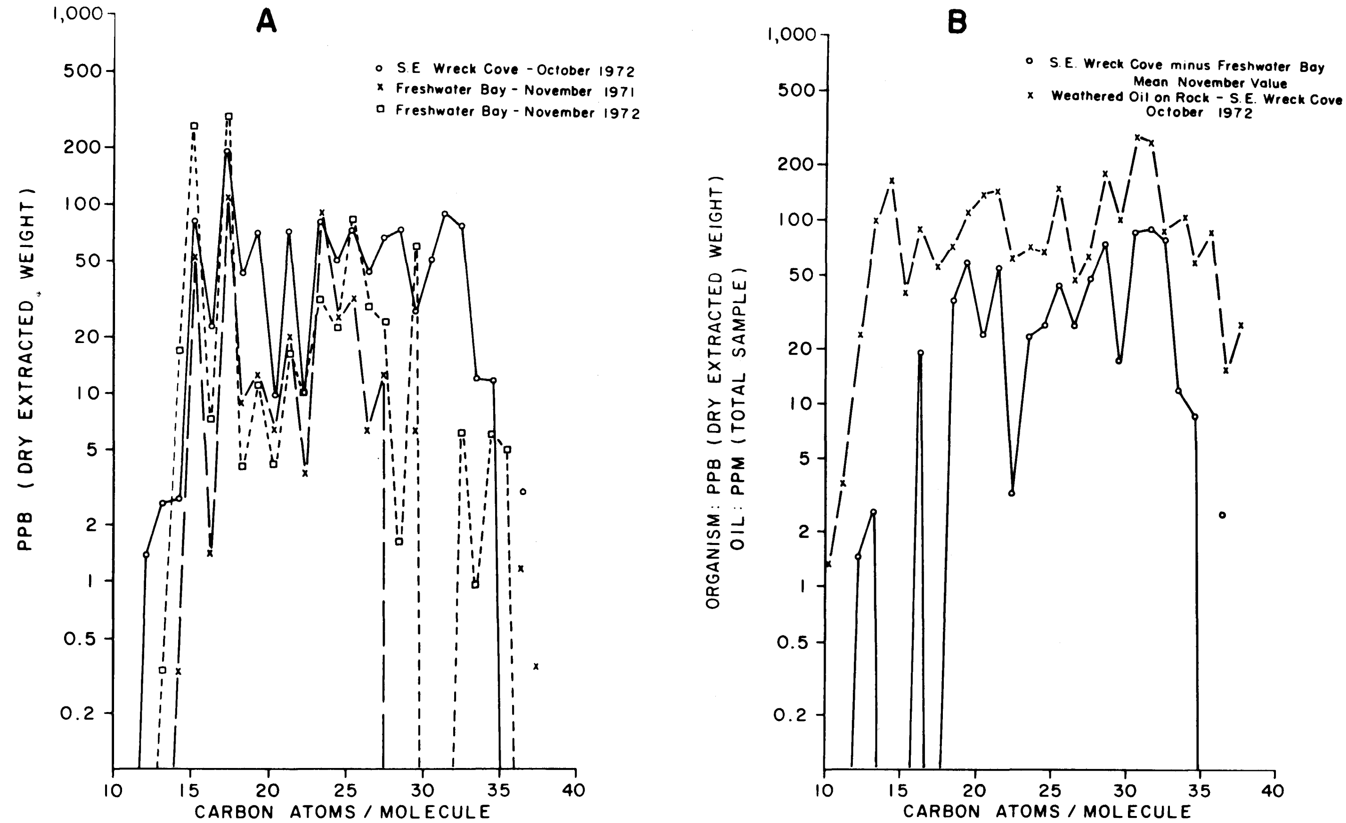


Figure 4. Paraffin hydrocarbon patterns for crabs (*Hemigrapsus nudus*) exposed to Navy Special Fuel Oil residues from the *General M.C. Meigs.* (A) Wreck Cove sample compared with control samples from Freshwater Bay (November 1971 and 1972). (B) The residual hydrocarbon pattern (Wreck Cove minus Freshwater Bay mean November value) compared with a weathered Navy Special Fuel Oil residue pattern.

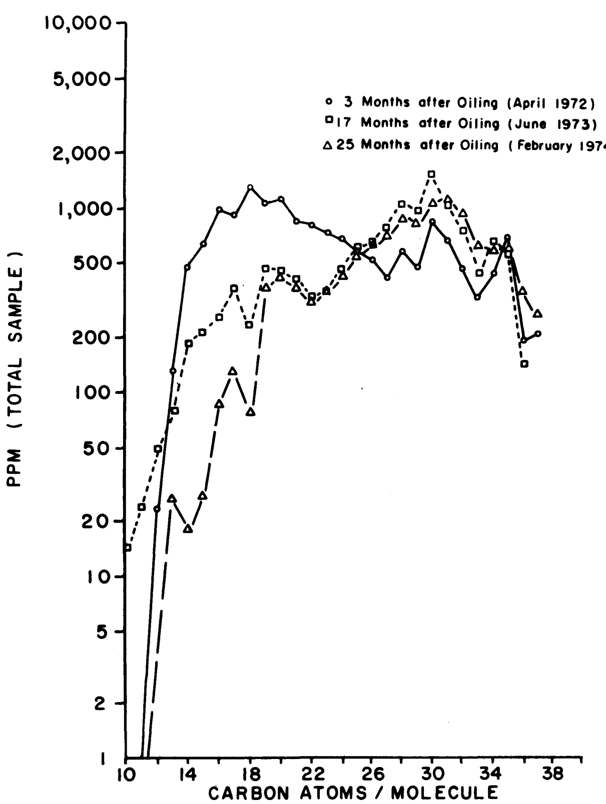


Figure 5. Paraffin hydrocarbon patterns of weathered Navy Special Fuel Oil residues from Picture Rock.

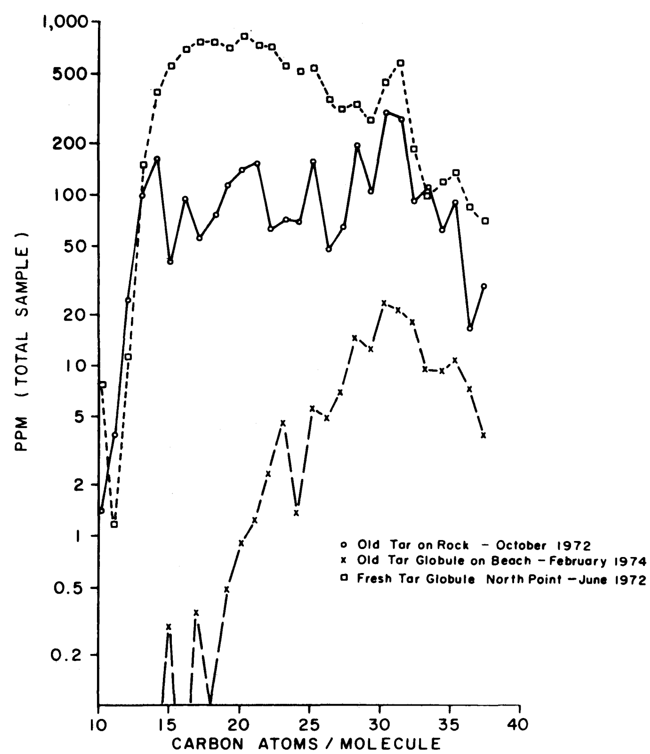


Figure 6. Paraffin hydrocarbon patterns of "old" Navy Special Fuel Oil residues from rocks and beach compared with a "fresh" residue from North Point.

Table 2. Animal species present at sampling sites 1 through 15 in Wreck Cove on January 20, 1973, July 27, 1973, and August 20, 1974

| PHYLUM Class Species | January 20, 1973 | July 27, 1973 | August 20, 1974 |
|---|---|---|---|
| COELENTERATA | | | |
| *Anthopleura elegantissima* | 1-4 | 1-7 | 4,8 |
| *Anthopleura xanthogrammica* | 1-12 | 1-15 | 1-15 |
| ECHINODERMA | | | |
| *Henricia leviuscula* | 4 | 12,15 | 1 |
| *Leptasterias hexactis* | 3 | 4-15 | 1-15 |
| *Pisaster ochraceus* | 1-12 | 4-15 | 1,5,8-15 |
| *Pycnopodia helianthoides* | - | - | - |
| *Strongylocentrotus purpuratus* | 3-12 | 8-15 | 4-15 |
| MOLLUSCA | | | |
| Amphineura | | | |
| *Tonicella* sp. | 8 | 3,8,13 | 4,15 |
| *Cryptochiton stelleri* | 8 | 4,15 | 15 |
| *Katharina tunicata* | 1-12 | 4-15 | 1-15 |
| *Mopalia muscosa* | 8 | - | - |
| *Mopalia* sp. | - | 1,4,12 | - |
| Nudibranchia | - | 4,12 | 15 |
| Pelecypoda | | | |
| *Entodesma saxicola* | 8 | 12 | - |
| *Venerupis staminea* | - | 8,15 | 1 |
| *Mytilus californianus* | 1,3 | 1,3 | 1,3,5 |
| Gastropoda | | | |
| *Acmaea mitra* | 3 | 15 | 15 |
| *Calliostoma ligatum* | 8 | - | 15 |
| *Ceratostoma foliatum* | - | 12 | - |
| *Diodora aspera* | - | - | 8 |
| *Crepidula adunca* | 3 | - | 1,3,8 |
| *Crepidula* sp. | - | - | - |
| *Littorina scutulata* | 1,5 | 1,2,3,5,13 | 1-12 |
| *Littorina* sp. | - | - | - |
| *Megatebennus bimaculatus* | 3 | - | - |
| *Searlesia dira* | 1-3 | 1,8,15 | 1,2,8 |
| *Tegula pulligo* | 1-3 | 1-12 | 1,2,8 |
| *Thais emarginata* | - | 1,4 | 1,3,8,9, 15 |
| *Thais lamellosa* | - | - | |
| Unidentified limpet | 2-5 | 1,3,4,12,15 | 1-12 |
| ARTHROPODA | | | |
| *Balanus cariosus* | 1,3 | 1,3,4 | 1,3 |
| *Balanus nubilis* | - | - | - |
| *Chthamalus dalli* | 1-12 | 1,13 | 1,5 |
| Decapoda | | | |
| *Hemigrapsus nudus* | - | 1 | 1 |
| *Lophopanopeus bellus* | - | 1,8,15 | - |
| *Oedignathus inermis* | 13 | - | - |
| *Pachycheles rudis* | 13 | - | 13 |
| *Pagurus hirsutiusculus* | - | - | - |
| *Pagurus* sp. | 1-8 | 1-15 | 1-12 |
| *Petrolisthes cinctipes* | - | - | 1 |
| *Pugettia producta* | 8 | 2 | 4 |
| *Pugettia gracilis* | - | 12-15 | 4-13 |
| Isopoda | | | |
| *Idothea wosnesenskii* | - | 1,4 | 1 |
| Amphipoda | - | 5 | 1 |
| CHORDATA | | | |
| *Styela gibbsii* | - | - | - |

**Sand and foam.** A sample of a dried brown-green foam residue at the high tide line was collected from Wreck Cove in October 1973 (21 months) after a fall storm. The analysis of this material shows an *n*-paraffin hydrocarbon pattern (figure 7; peaks at 25, 28, 30-31, 35 and troughs at 26, 29, 34, 36) similar to a petroleum sample above $C_{22}$, as well as possible biological material (peaks at 15 and 17 slightly above the normally-smooth petroleum-like distribution).

A sand sample collected immediately beneath Picture Rock in August 1972 displays a much less petroleum-like pattern although the major components above $C_{22}$ have the basic shape of the pollutant (peaks at 25, 28, 30-31 and troughs at 26-27, 29, 34). Below $C_{22}$ the pattern probably reflects degraded pollutant and biogenic contributions from the fauna in the sand. We had no similar sand samples to serve as uncontaminated controls.

For comparison we have also presented the pattern (figure 7) and calculations (table 1) for Navy Special Fuel Oil obtained as a composite tank sample at the U.S. Navy Fuel Supply Depot Manchester (Washington) in 1971. This material can be used for rough comparison but not as an absolute reference to the *General M. C. Meigs* spill. The latter had been in the fuel tanks since before 1958 at which time the light ends had been stripped off by forced ventilation of the fuel compartments prior to mothballing.

**Persistent release of oil.** We have observed "fresh" tar globules, usually about 10 cm in length and breadth and about 6 cm thick, during every survey of Wreck Cove although the quantity in summer and fall is much lower than in winter and spring. Fresh tar globules are characteristically shiny and have a tacky black surface giving off a strong petroleum odor. We analyzed these globules (figure 8) and found that, with the exception of the sample collected in February 1974 which does not display the same smooth shape below $C_{22}$, they have similar *n*-paraffin patterns.

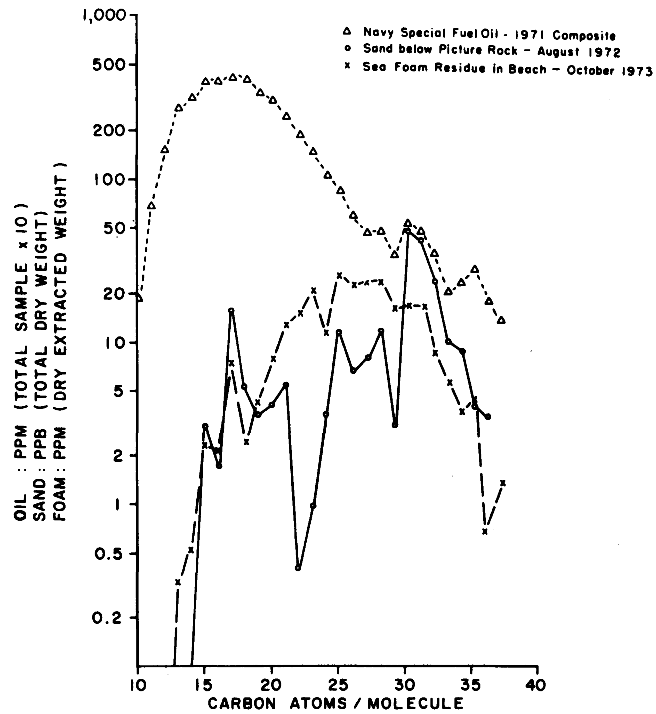


Figure 7. Paraffin hydrocarbon patterns of whole Navy Special Fuel Oil from a composite tank sample at the U.S. Navy Supply Depot Manchester (1971) compared with patterns obtained from extraction of sand collected below Picture Rock and of sea foam residue found at the high tide line in Wreck Cove in October 1973.

We believe that throughout our survey period we were being confronted with residues from the Navy Special Fuel Oil which has been released continually and specifically from the *General M. C. Meigs* and that the reasonable similarity of the original *n*-paraffin hydrocarbon patterns of the oil to subsequent patterns tends to confirm our belief.

**Weathering parameters.** We have calculated a number of parameters from the gas chromatographic data by the methods described in Blumer et al. [5] to show environmental weathering of some of our oil samples (table 4). We calculated the equivalent *n*-paraffin carbon numbers where the evaporative losses reached 50% ($C_n$50%) and 10% ($C_n$90%) based on the unresolved envelope under the *n*-paraffin peaks on each chromatogram. In the samples from Picture Rock one can see the increase in carbon number for these parameters with increased aging. The old tar globule of February 1974 had weathered significantly as had the oil contributed to the sea foam and sand samples.

The *n*-heptadecane/pristane (17 pris) and *n*-octadecane/phytane (18/phyt) ratios can be used as measures of microbial degradation since the ease of degradation decreased from *n*-alkanes to *cyclo*-alkanes to aromatics [6].

Similarily the magnitude of the unresolved background to the *n*-paraffin peaks at $C_{20}$ and $C_{27}$ can be used to show *n*-paraffin loss (20/Bk and 27/Bk). The decrease in these four values with aging at Picture Rock probably shows slow microbial modification and tends to confirm visual evidence that this rock received no further oilings. The sample of fresh tar globules collected in June 1972 from North Point had undergone less weathering than the sample collected in Wreck Cove at the same time, while those in June 1973 and February 1974 were also somewhat more weathered.

**Table 3. Counts of prominent animals within grids at a sampling site for three surveys at Wreck Cove**

| | SAMPLING SITES 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 12A | 13 | 14 | 15 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| January 20, 1973 | | | | | | | | | | | | | | | | |
| Small barnacles – live | 47 | 126 | 61 | 50 | 93 | - | - | - | 17 | - | - | 10 | - | - | - | - |
| dead | 16 | 9 | 12 | 6 | 23 | - | - | - | 3 | - | - | 7 | - | - | - | - |
| Large barnacles – live | - | - | 1 | - | - | - | - | - | - | - | - | - | - | - | - | - |
| dead | - | - | 2 | - | - | - | - | - | - | - | - | - | - | - | - | - |
| Mussels – live | 82 | - | 63 | - | - | - | - | - | - | - | - | - | - | - | - | - |
| dead | 5 | - | 1 | - | - | - | - | - | - | - | - | - | - | - | - | - |
| Snail: T. emerginata | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| Snail: Littorina sp. | 11 | 4 | 20 | 9 | 15 | - | - | - | - | - | - | - | - | - | - | - |
| Limpet | - | 10 | 3 | - | 17 | - | - | - | - | - | - | - | - | - | - | - |
| Anemone | - | - | - | - | 4 | - | - | 5 | 6 | - | - | 4 | 10 | - | - | - |
| Urchin | - | - | - | - | 1 | - | - | 18 | 4 | - | - | 13 | 89 | - | - | - |
| July 27, 1973 | | | | | | | | | | | | | | | | |
| Small barnacles – live | 38 | 79 | 143 | 61 | 73 | - | - | - | 11 | - | - | 35 | - | - | - | - |
| dead | 26 | 3 | 9 | 6 | 8 | - | - | - | 8 | - | - | 5 | - | - | - | - |
| Large barnacles – live | - | - | 1 | - | - | - | - | - | - | - | - | - | - | - | - | - |
| dead | - | - | 2 | - | - | - | - | - | - | - | - | - | - | - | - | - |
| Mussels – live | 91 | - | 66 | - | - | - | - | - | - | - | - | - | - | - | - | - |
| dead | 1 | - | 0 | - | - | - | - | - | - | - | - | - | - | - | - | - |
| Snail: T. emarginata | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| Snail: Littorina sp. | 4 | 1 | 14 | - | 5 | - | - | - | - | - | - | - | - | - | - | - |
| Limpet | 1 | 4 | 12 | - | 4 | - | - | - | - | - | - | 1 | - | - | 2 | - |
| Anemone | - | - | - | - | 3 | - | - | 1 | 6 | - | - | 3 | 11 | - | - | - |
| Urchin | - | - | - | - | - | - | - | 7 | - | - | - | 11 | 71 | - | 11 | 39 |
| August 20, 1974 | | | | | | | | | | | | | | | | |
| Small barnacles – live | 133 | 38 | 220 | 32 | 12 | - | - | - | 22 | - | - | 33 | - | - | - | - |
| dead | 4 | 0 | 0 | 3 | 29 | - | - | - | 2 | - | - | 5 | - | - | - | - |
| Large barnacles – live | - | - | 2 | - | - | - | - | - | - | - | - | - | - | - | - | - |
| dead | - | - | 2 | - | - | - | - | - | - | - | - | - | - | - | - | - |
| Mussels – live | 78 | - | 45 | - | - | - | - | - | - | - | - | - | - | - | - | - |
| dead | 1 | - | 0 | - | - | - | - | - | - | - | - | - | - | - | - | - |
| Snail: T. emarginata | 5 | - | 2 | - | - | - | - | - | - | - | - | - | - | - | - | - |
| Snail: Littorina sp. | 65 | 3 | 40 | - | - | - | - | - | - | - | - | - | - | - | - | - |
| Limpet | 6 | 2 | 7 | - | - | - | - | - | - | - | - | - | - | - | - | - |
| Urchin | - | - | - | - | 2 | - | - | 5 | 1 | - | - | 5 | 10 | - | - | - |
| | - | - | - | - | - | - | - | 12 | - | - | - | 19 | 56 | - | - | - |

**Table 4. Analytical parameters for evaluating of weathering of petroleum residues from the *General M. C. Meigs***

| Sample | $C_n^{90\%}$ | $C_n^{50\%}$ | $\frac{17}{Pris}$ | $\frac{18}{Phyt}$ | $\frac{20}{Bk}$ | $\frac{27}{Bk}$ |
|---|---|---|---|---|---|---|
| Picture Rock | | | | | | |
| Aged 3 months | 11.6 | 14.4 | 2.3 | 3.2 | 1.8 | 1.2 |
| Aged 17 months | 13.4 | 17.9 | 1.6 | 0.8 | 1.3 | 1.3 |
| Aged 25 months | 14.6 | 17.5 | 0.3 | 0.1 | 1.3 | 1.5 |
| "Old" tar globules | | | | | | |
| on rock–October 1972 | 12.3 | 17.6 | 0.7 | 0.8 | 1.1 | 1.0 |
| on beach–February 1974 | 18.3 | 25.3 | * | * | 1.1 | 1.2 |
| "Fresh" tar globules | | | | | | |
| North Point–June 1972 | 11.5 | 14.1 | 1.7 | 2.7 | 2.3 | 1.3 |
| S.E. Wreck Cove–June 1972 | 11.1 | 16.0 | 1.0 | 1.7 | 1.5 | 1.1 |
| S.E. Wreck Cove–June 1973 | 11.2 | 17.1 | 0.5 | 1.5 | 1.2 | 1.0 |
| S.E. Wreck Cove–Feb. 1974 | <10 | 17.6 | 0.6 | 1.0 | 1.3 | 1.1 |
| Sea foam–October 1973 | 13.9 | 18.5 | 0.2 | 0.6 | 1.2 | 1.3 |
| Picture Rock sand–Aug 1972 | 16.9 | 21.5 | 2.2 | * | 1.1 | 1.1 |
| Whole Navy Special Fuel Oil | 10.4 | 11.7 | 1.6 | 4.1 | 2.8 | 1.4 |

*not detected

An extensive discussion of the application of these parameters to the understanding of the weathering processes of identified petroleum residues on a beach has been given by Blumer and coworkers [5].

## SUMMARY AND CONCLUSIONS

From our analyses we found that petroleum residues were detectable in certain marine fauna for at least nine months after the initial wreck and oil spill, whereas in specific algae species, residues remained for more than a year. Two difficulties in assessing petroleum pollutant uptake and loss in this spill are that the oil has been released continually over the entire 31-month period of our study and that the quantity of oil obviously fluctuated seasonally with winter storms in a manner we have no means of estimating.

The long-term occurrence of the contamination in organisms is possibly the result of periodic recontamination by the tar globules in combination with the persistance of the original large petroleum uptake immediately after the grounding. Our methods do not permit us to differentiate between the two types of contamination. The hydrocarbon pollutant patterns represented by the residual paraffin patterns of the organisms reflect the degree of pollution throughout the sampling period.

The weathering of oil residues is dependent upon the variations of environmental conditions to which the oil is exposed; however, most of the weathered oil we sampled showed a basic uniformity in *n*-paraffin hydrocarbon patterns.

Pathological effects from oil on organisms were evident primarily in the purple urchin (*Strongylocentrotus purpuratus*). During the first ten months of observations following the grounding, many urchins in localized areas were dead or had lost enough of their spines to make their survival improbable [1]. Subsequent observations revealed that damage to the urchin population decreased with time, and on the final survey of August 1974 no damaged urchins could be found.

Population studies comparing numerical abundance in March 1972 with those in August 1974 showed no significant differences other than those attributable to normal season variations. Few changes were noted in abundance in the first ten months after the accident [1], but a slight decline in number of animals was observed after this ten month period. For example, a colony of anemones

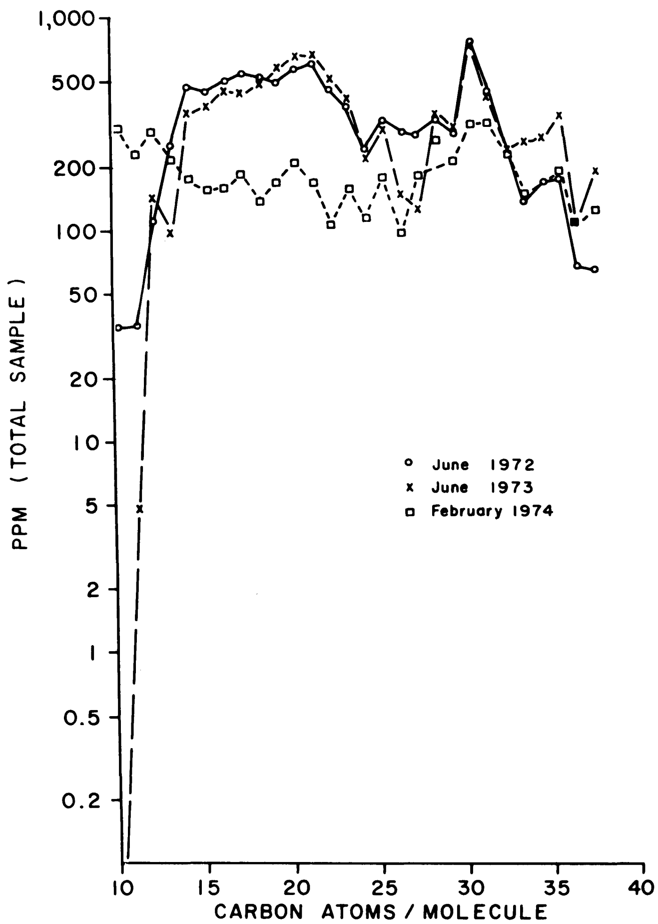


Figure 8. Paraffin hydrocarbon patterns of "fresh" Navy Special Fuel Oil residues from Southeast Wreck Cove.

(*Anthopleura elegantissima*) at station 4 reflected this decline in numbers. It might be that the breakwater effect of the hulk provided a greater growth potential for algae that competed with intertidal animals for the same substrate.

Lack of dramatic change in speciation or numerical abundance of intertidal or motile animals suggests the oil spill had few pronounced or long-term adverse effects that our methods detected. The August 1974 survey indicated that the area affected by the impact of the grounding and oil spillage from the *General M. C. Meigs* has returned to an apparently normal state as determined by our level of investigations.

## ACKNOWLEDGMENTS

The authors wish to thank the officers and enlisted men of the Makah Air Force Station (758th Radar Squadron – SAGE) for on-site assistance. We also appreciate the advice and assistance of J. C. Willman (Environmental Protection Agency), Harry Tracy (Department of Ecology), R. Scully, and H. Williams.

## REFERENCES

1. Clark, R.C., Jr.; Finley, J.S.; Pattern, B.G.; Stefani, D.F.; and DeNike, E.E. 1973. Interagency investigations of a persistent oil spill on the Washington Coast: animal population studies, hydrocarbon uptake by marine organisms, and algae response following the grounding of the troopship *General M.C. Meigs*. *Proceedings of Joint Conference on Prevention and Control of Oil Spills,* March 13-15, 1973, pp. 793-808. Washington, D.C.: American Petroleum Institute.
2. Clark, R.C., Jr., and Finley, J.S. 1973. Techniques for analysis of paraffin hydrocarbons and for interpretation of data to assess oil spill effects in aquatic organisms. *Proceedings of Joint Conference on Prevention and Control of Oil Spills,* March 13-15, 1973, pp. 161-172. Washington, D.C.: American Petroleum Institute.
3. Clark, R.C., Jr., and Finley, J.S. In press. Analytical techniques for isolating and quantifying petroleum paraffin hydrocarbons in marine organisms. In *Proc. Marine Pollution Monitoring (Petroleum) Symposium,* pp. 96-101. Washington, D.C.: National Bureau of Standards.
4. Blumer, M., and Sass, J. 1972. Oil pollution: persistence and degradation of spilled fuel oil. *Science* 176: 1120-22.
5. Blumer, M.; Ehrhardt, M.; and Jones, J.H., 1973. The environmental fate of stranded crude oil. *Deep-Sea Res.* 20: 239-259.
6. ZoBell, C.E. 1969. Microbial modification of crude oil in the sea. *Proceedings of Joint Conference on Prevention and Control of Oil Spills,* pp. 317-326. Washington, D.C.: American Petroleum Institute.