Scuba Techniques Used to Assess the Effects of the Exxon Valdez Oil Spill

Stephen C. Jewett
Institute of Marine Science, University of Alaska Fairbanks,
P.O. Box 757220, Fairbanks, AK 99775-7220, 907-474-7841 (tel.),
907-474-7204 (fax), jewett@ims.uaf.edu

Thomas A. Dean
Coastal Resources Associates, Inc.,
1185 Park Center Drive, Suite A, Vista, CA 92083

Max K. Hoberg
Institute of Marine Science, University of Alaska Fairbanks,
P.O. Box 757220, Fairbanks, AK 99775-7220

In March 1989, the T/V Exxon Valdez ran aground in Prince William Sound (PWS), Alaska, and spilled nearly 42 million liters of crude oil. About half of the oil became stranded on the shoreline, and an estimated 13% was deposited in subtidal sediments. Because the shallow subtidal regions of PWS are mosaics of habitats, from sheltered muddy bays dominated by eelgrass to exposed rocky points dominated by kelps, it was not feasible to assess the damage from the spill using standard shipboard sampling techniques. Instead, scuba techniques were implemented to assess damage and monitor recovery of subtidal communities. The Exxon Valdez Oil Spill (EVOS) Trustee Council sponsored two multi-year investigations that utilized research diving: (1) the effects of the spill on shallow subtidal communities (1989-95); and (2) mechanisms of impact and potential recovery of nearshore vertebrate predators following the spill (1995-99). The following is a synopsis of scuba techniques and methodologies used to assess and monitor the effects of the spill in the shallow (generally <20 m) subtidal regions of PWS (Table 1).
Table 1. Scuba sampling that occurred on two multi-year investigations relative to the Exxon Valdez oil spill.

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<td>Eelgrass</td>
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<td>Measure 20 stipe diameters 1 m off bottom in 4 x 30 m transects</td>
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<th>Sample type</th>
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Effects on Shallow Subtidal Communities (1989-1995)

Sampling Design and Methods

For most of our studies on the subtidal communities, we used a stratified random sampling design to determine the effects of the spill and monitor recovery. We measured population parameters (e.g., abundance, biomass, diversity, reproductive success) for the dominant plant, invertebrate, and fish species at both oiled and control sites. Five habitats were investigated in the Knight Island archipelago of western PWS: Zostera marina (eelgrass) beds, Laminaria/Agarum (brown algae) beds both in bays and on points, Nereocystis (brown alga) beds, and silled fjords. These habitats were defined with respect to dominant plants, physiography, and location within the sound to ensure that variance due to factors other than oil was minimized, thereby increasing the power to detect differences among oiled and control sites. Zostera dominates in areas of soft substrate that generally occur in back bays in the vicinity of mouths of streams. Nereocystis (bull kelp) dominates on points in more exposed areas with strong currents. While Nereocystis habitats are relatively rare in PWS, they represent habitats of special significance, with high diversities of algae, epifaunal invertebrates, and nondemersal fishes. Few (<6) silled fjords occur in the vicinity of Knight Island. Below the shallow zones of Zostera and Laminaria/Agarum in fjords, the substrate mainly consists of a dense layer of flocculent detritus over mud. The Laminaria/Agarum habitat is the most widely represented nearshore habitat in the sound.

Sites within habitats were initially chosen based on an overlay of oil information and habitat information on navigational charts. From those oiled areas for each habitat, a 200 m section of shoreline was selected for sampling. Control sites were selected that were indicated as not oiled in two earlier oil surveys. Controls were matched with selected oiled sites as closely as possible with regard to aspect, proximity to sources of freshwater input, slope, wave exposure, and water circulation.

The sampling effort within each habitat was stratified by depth. In the Zostera habitat, three strata were selected: 3-6 m, 6-20 m, and at the midpoint of the Zostera bed (generally <3 m) (Figure 1). In the Laminaria/Agarum habitats two strata were selected: 2-11 m and 11-20 m. The sampling stratum within the Nereocystis habitat was 2-8 m, the depth range for Nereocystis. Sampling in silled fjords occurred at 20 m depths. At each Zostera and Laminaria/Agarum site, we randomly established three 30 m transects within each depth stratum. Up to six transects per site were established in the Nereocystis habitat.

Fishes and large epifaunal invertebrates were counted along each 30 m transect. Two divers swam each transect and counted fishes and invertebrates by species within 1 m on either side of the transect line and within 3 m off the bottom. All observations were recorded on data sheets under water. Fishes mainly belonged to nine families. Large invertebrates were
mainly the helmet crab (*Telmessus cheiragonus*) and five species of sea stars.

Four 0.25 m$^2$ quadrats were randomly placed along each transect to assess *Zostera* or algae. *Zostera* turions (above-sediment portions of the plant arising from the rhizome, usually with four or five leaves attached) and flowering stalks were counted, with slight modifications in technique from year to year. The percent cover of understory algae, mainly *Laminaria/Agarum*, was determined for each quadrat. All algae greater than 10 cm in height were collected from the quadrats and returned to the boat where each individual was identified, weighed, and measured. *Nereocystis* density was determined by counting all plants greater than 2 m in height within a 4 m swath along transects. The size distribution of *Nereocystis* was determined by measuring the diameter of the stipe, at a distance 1 m above the bottom, for the first 20 plants observed along each transect. The relationship between stipe diameter and total wet weight was determined by weighing and measuring the stipe diameter of each plant from 20 to 40 plants collected from each site. The analysis of these data indicated that stipe diameter was an excellent predictor of weight.

Infaunal invertebrates in *Zostera* and *Laminaria/Agarum* habitats were collected from two 0.1 m$^2$ quadrats randomly placed along each 30 m transect. Samples were collected to 10 cm sediment depths by divers using a suction dredge. In the *Zostera* bed, eelgrass shoots were cut off above the sediment surface and removed prior to taking the suction dredge samples. The dredge sampler was fitted with a collection bag with a mesh size of 1 mm.
Divers also collected two sediment samples from each transect. One of the samples was used to determine sediment grain-size composition and the other to determine hydrocarbon concentrations.

**Determining Growth Rates of Seive Kelp Agarum clathratum (Jewett et al. 1995)**

The growth rate of Agarum was determined at two pairs of oiled and control sites in the summer of 1990. At a depth of 8 m at each site, 20 plants between 50 and 100 cm in height were selected. All plants were within two 2 x 30 m swaths and were separated by 1 to 2 m. Each plant was marked by driving a steel spike, with a numbered plastic tag attached, into the seafloor next to each plant. A small piece of plastic surveyors flashing was placed through a hole near the midrib at a height approximately 10 cm above the juncture of the holdfast and the blade. We then measured and recorded this distance. Surrounding plants within a radius of about 1 m were removed in order to eliminate potential competition. After a period of 41 to 57 days, the stations were revisited and the distance from the bottom of the blades to the tag was remeasured and recorded. The growth of each plant was calculated as the change in distance from the base of the blade to the tag over the 41 to 57 days. All measurements were standardized to the growth (in cm) per 30 days.

**Experimental Studies with the Mussel Musculus (Jewett et al. 1995)**

Experiments were conducted in Herring Bay in 1993 to examine the effects of Musculus spp. on Zostera and to examine the effects of predation on the distribution and abundance of Musculus. Studies in 1990 demonstrated that Musculus was more abundant at oiled sites, Zostera was more abundant at control sites, and that potential predators of Musculus were more abundant at control sites. We hypothesized that densities of Musculus were higher at oiled sites because abundances of predators (especially the crab Telmessus and the sea star Dermasterias) were lower there, and that higher densities of Musculus at oiled sites led to a reduction in Zostera density.

The first experiment was designed to test the hypothesis that Musculus inhibited the growth of Zostera. Ten 1 m² plots were established within the Zostera bed at Herring Bay, where densities of Musculus averaged about 40,000 m². The plots were placed about 2 m apart along two 20 m long lines laid within the Zostera bed. All Musculus were removed from 5 randomly selected plots. Divers gently rubbed the blades of the Zostera and then collected the mussels using an airlift. The remaining five plots served as unmanipulated controls.

The initial removal was conducted on 17 and 18 July 1993. Approximately two months later, we revisited the site and collected all of the Zostera blades within a 0.25 m² area within each plot. After collection, we
counted the number of *Zostera* turions and the number of *Musculus* on the *Zostera*.

A second experiment was conducted to test the hypothesis that the abundance of *Musculus* could be locally limited by predation, especially predation from the crab, *Telmessus*, and from the sea star, *Dermasterias*. Two 30 m long transect lines were established within the *Zostera* bed at Herring Bay. A total of 10 1 m diameter plots were established at equal distances along each line. The plots were randomly assigned one of five treatments: predator exclusion (caged), *Dermasterias* inclusion (caged with a *Dermasterias* enclosed), *Telmessus* inclusion (caged with a *Telmessus* enclosed), cage control (a partial cage), and a control (no cage). The cages used were 1 m in diameter hoop nets that were approximately 1 m tall and were constructed with 2.5 cm mesh nylon netting. The bottom hoop of each cage was secured to the bottom using U-shaped steel reinforcement bar “staples.” The net was maintained in an upright position by placing small fish-net floats on the upper two rings of the hoop net. The cage control consisted of a cage, but with one-half of the netting of the hoop cut out. The netting was removed such that there were two panels of netting separated by two areas where the netting was removed.

*Telmessus* and *Dermasterias* were collected by hand from the surrounding areas within Herring Bay and one animal each was placed in their respective cages. The *Telmessus* were approximately 8 cm in carapace width and the *Dermasterias* were about 15 cm from ray tip to ray tip. The animals were placed into cages on 18 July 1993. Approximately two months later, on 26 September 1993, the site was revisited and all *Zostera* within each cage were sampled by divers and placed into a small mesh bag under water. Care was taken to place the *Zostera* blades into the bags without dislodging any *Musculus* that may have been attached. The samples were preserved in formalin and later the number of *Zostera* blades and *Musculus* in each sample were counted.

**Mechanisms of Impact and Potential Recovery of Nearshore Vertebrate Predators (NVP)**

(1995-1999)

Scuba was used to assess several factors potentially constraining the recovery of four nearshore vertebrate predators—sea otters, river otters, harlequin ducks, and pigeon guillemots—“injured” by the EVOS. Prey groups of these predators were examined from oiled and unoiled locations. The oiled area was along northern Knight Island, at Herring Bay, and Bay of Isles. The unoiled area was along the northwestern Montague Island. Within each study area, potential sampling sites were chosen by selecting a random starting point, then systematically dividing the shoreline into sequential intervals of 600 m length throughout the rest of the study area. Sampling segments were chosen at regular intervals, beginning at the ran-
Sampling starting point. Sampling by divers occurred along 200 m shoreline segments within selected sites.


Three sea otter subtidal prey categories (clams, crabs, and sea urchin) were targeted in the NVP study. Emphasis was placed on prey sizes typically taken by otters, i.e., clams \(\geq 20\) mm, crabs \(\geq 50\) mm carapace width, and urchins \(\geq 15\) mm diameter. Clams were sampled within a randomly chosen subset of the 200 m segments selected for intertidal sampling. Two depth strata (10 and 20 m) were sampled at each site using a Venturi suction dredge. The dredge hose and nozzle were dropped in the appropriate depth stratum at each site and a 15 m transect tape was laid on the bottom substratum along the depth contour, beginning where the nozzle came to rest on the seafloor. A steel quadrat frame of \(0.5 \times 0.5\) m was placed along the transect tape at a random starting point with the first 3 m of the tape. Three to five replicate quadrats \(3\) m apart were dredged, generally to about 0.5 m. All clams excavated by the dredge were collected and placed into mesh bags.

Crabs, mainly *Telmessus*, and sea urchins were sampled within two depth strata, 0-5 m and 5-10 m, since previous information indicated *Telmessus* and urchins were mainly found at these depths. The sampling depths at each site were randomly selected within each depth stratum. Transects were 0.5 m in width and 200 m in length, running parallel to shoreline. Divers swam along transects and collected all crabs and urchins. All crabs and the first 100 urchins encountered at each site were measured for length-frequency distributions.

**Sampling Sea Otter Prey Competitors (Gage 1998)**

Scuba sampling in this component of the NVP study was designed to test the hypothesis that high rates of clam consumption by predatory invertebrates were limiting the size of clam populations in oiled areas, and consequently, the local recovery of sea otters from EVOS. Subtidal sampling of invertebrate predators in summer and winter was conducted adjacent to randomly selected 200 m transects from oiled (Herring Bay and Bay of Isles) and unoiled (northwest Montague Island) areas. Depths sampled were 4, 7, and 10 m. A buoy line was dropped to locate the starting point at 4 m in depth. Divers laid out a transect tape perpendicular to shore, from 4 m to 10 m in depth. This line is referred to as the "mainline." A depth of 7 m was marked on the mainline as it was laid out. Divers determined 7 m and 10 m in depth using depth gauges. Transect lines were set out perpendicular to the mainline extending 10 m in either direction at 4, 7, and 10 m. Transects followed the depth contours. Invertebrate predators located within 1 m either side of the transect line were sampled. The sampled plots were 40 m² in area for each depth.
Divers recorded substrate type and temperature, and water samples were collected for salinity determination. Divers recorded observed activity and invertebrate predator species (snails, crabs, and sea stars) on underwater data sheets. Activity was categorized as digging, feeding, having an extended stomach (for sea stars), escaping (for crabs), inactive, or moving. Diets were recorded during sampling dives for all invertebrate predators that were observed actively feeding in the sampling plots. Additional diet determinations were made at the surface and in the laboratory. All specimens were measured at the surface.

**Sampling River Otter Subtidal Prey (Bowyer et al. in press)**
Nearshore demersal fishes were sampled at 30 latrine sites used by river otters for both Herring and Jackpot bays in July 1996-1997, as well as 30 random sites at each location in both years. Demersal fishes were counted along two transects oriented perpendicular to shore by two scuba divers. Transects extended 30 m, or in instances where the tidal zone was steep, until a depth of 15 m was reached. The two transects at each site were separated by 20 m and originated 10 m to either side of the center of a particular site. Fishes in the water column were counted over a 2 m wide swath. Demersal fishes were counted along a 1 m wide swath on each transect while gently moving aside algae and other vegetation. All fishes counted were classified into three size classes (<8 cm, 8-15 cm, >15 cm total length) and were identified to family.

Divers also conducted a fish removal experiment (see Blundell et al. 2001, this volume).

**Sampling Harlequin Duck Prey (Esler et al. 2000)**
Sampling for harlequin duck subtidal foods was conducted beside 23 200 m shoreline sites. Samples (0.25 m² quadrat) were obtained at three locations at each of two depths (0.5 to -0.5 m and -0.5 to -1.5 m MLLW) (mean lower low water) along each of the 200 m shoreline sites. At each quadrat, divers collected and bagged all algae or eelgrass and scraped all visible epifauna from the substrate and airlifted them into a mesh bag. Epifauna were later scraped from algae and eelgrass, combined with epifauna from substrate, sorted, and identified to seven prey types (limpets, chitons, lacunid snails, littorine snails, other snails, amphipods, and other crustaceans).

**Sampling Pigeon Guillemot Prey (Golet et al. in press)**
Dive transects were performed at guillemot foraging areas near the study colonies. Demersal fish population densities were established in 1996 and 1997. A total of 60 sites were surveyed (15 per area-year). Sites were systematically selected within a 4 km radius of major guillemot nesting areas. At each site, we counted demersal fishes along two transects running
perpendicular to shore. Transects extended a distance of 30 m, or in cases where the shoreline was steep, until a depth of 15 m was attained. The two transects at each site were separated by 20 m and originated 10 m to either side of the center of the site. Demersal fishes were counted along a 1 m wide swath on each transect while moving aside algae and other vegetation. All fishes <15 cm were identified to family, and classified as one of two size classes (1-8 cm and 8-15 cm). For comparison purposes the average density (fish per 100 m²) was calculated for each fish family in each area.

**Research Diving Statistics**

In the 10-year period (1989-1998) of research diving on the two multiyear EVOS projects, 26 divers made 4,315 dives for approximately 2,068 hours of bottom time. Only one diving incident occurred: a Type I DCS in 1991. This diver was treated on a Navy Table 6 and was cleared to resume diving following a two-week suspension of diving.

**References**


