

SPEC

Canadian Scientific Pollution & Environmental Control Society
1603 West 4th Avenue, Vancouver, B.C. V6J 1L8
Telephone 736-5601



THE POSSIBLE EFFECTS OF THE
PROPOSED PORT EXPANSION AT
ROBERTS BANK ON THE ECOLOGY
OF SALMON, WATERFOWL, BENTHIC
ORGANISMS AND CRABS
IN THE AREA

Valentin Schaefer, M.Sc., Ph.D. (pending Senate approval)
Graduate Student
Department of Biology
Simon Fraser University

SUPPLEMENTAL WRITTEN SUBMISSION
OF THE CANADIAN SCIENTIFIC
POLLUTION AND ENVIRONMENTAL
CONTROL SOCIETY (SPEC)
TO THE PUBLIC HEARINGS ON
ROBERTS BANK PORT EXPANSION

October 24, 1978



INTRODUCTION

This report investigates the possible effects that the proposed port expansion at Roberts Bank will have on the ecology of the area. It considers possible effects of the construction and operation of four additional facilities on salmon, waterfowl, benthic organisms and crabs.

References for the information presented are provided as much as possible. These references are mainly secondary due to time restrictions in the preparation of this report; they have not been read by the author. The literature considered comprised for the most part the technical reports of the Westwater Research Centre, and a report prepared for the West Coast Oil Ports Inquiry, from which most of the secondary references were taken. The secondary references are mentioned in the text merely for convenience so the reader need not consult the primary sources.

Two aspects of the proposed port expansion have been dealt with:

- 1) the habitat destruction of organisms due to the construction of the facilities;
- 2) the pollution (mainly oil pollution) which will result from the estimated six-fold increase in freighter traffic serving the facilities.

Both aspects are of importance to the ecology of Roberts Bank and surrounding areas.

SALMON

There are considerable numbers of juvenile salmon found near and over the tidal flats of Roberts Bank during spring and summer months. Chinook are the most common in the area, comprising 82% of the young salmon (Goodman 1975).

The habitat of Roberts Bank is in itself important to salmon for several reasons. These include (after Northcote et al 1978) :

1) Nutrient Supply : The decomposition of organic matter occurring on the bank provides food sources to the organisms on which salmon feed directly, or to others of the food chain. The abundance of chinook salmon has been demonstrated to be controlled by the food web (Sibert et al 1977);

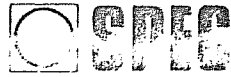
2) Acclimation : Coho and chinook salmon may use Roberts Bank as an area for physiologically adjusting from fresh water to salt water.

3) Predator Refuges : Salmon fry may hide from smolts and sculpin in the eelgrass beds to avoid predation.

The question of nutrient supply is of particular importance.

~~Large numbers of juvenile salmon~~ not actually utilizing the area of Roberts Bank that would be directly affected by port expansion would nevertheless be seriously affected by port expansion because of their dependence on organisms at lower levels of the food web.

Another important role which Roberts Bank may play in the survival of salmon is the provision of an important feeding area before their migration into the North Pacific Ocean. This pre-migration feeding would encourage rapid growth and thus enhance the future survival of the salmon because they would be "healthier". There is as yet no scientific evidence to indicate that this is in fact the case.



However, before any further habitat destruction occurs on Roberts Bank, data should be collected to clarify the matter.

Feeding is an important issue because it is involved in the Salmonid Enhancement Program currently being undertaken jointly by the Federal and Provincial Governments. It should be remembered that Canada is not the only country currently engaged in a salmon enhancement program. Similar programs are underway in Japan, Alaska, Washington and Oregon. It is not known whether the North Pacific can support the additional numbers of salmon, and the issue will probably not be resolved for ten to fifteen years. There may be considerable competition for resources in the North Pacific among salmon in the near future, and if the salmon are in a better or "healthier" condition when they arrive they will probably be in a better position to survive. In other words, Fraser River salmon might be able to survive even if key feeding areas on Roberts Bank were degraded or destroyed, but in the long term may not be strong or healthy enough to survive in the competition for resources in the North Pacific. Roberts Bank may play an integral role in the viability of the Salmon Enhancement Program in the 1980's.

Data on the distribution of juvenile salmon in the Fraser Estuary is available (Goodman 1975). Tow net catches for juvenile chinook were roughly ten times greater at sites on the nearshore marsh areas of Roberts and Sturgeon Banks than at sites on the sloughs or open water areas of the lower mainstem River (New Westminster to Sandheads), and roughly five times greater at sites on the open water (mid-tide) areas of Roberts and Sturgeon Banks. Tow net catches for juvenile coho were roughly five times greater at nearshore marsh sites and twice as great at open water sites on Roberts and Sturgeon Banks than at sites on the lower mainstem River. It would seem that Roberts Bank is a "preferred" area of utilization by juvenile chinook and coho salmon.

The importance of eelgrass beds such as those located in the immediate vicinity of the Roberts Bank superport has been well expressed by Beak Hinton Consultants in the Environmental Impact Statement which they prepared on Roberts Bank Port Expansion. As colonizers of soft substrate, the plants reduce surface erosion and the leaves reduce currents thus increasing sedimentation rates of organic and inorganic material. The eelgrass leaves support epiphytes which are grazed upon by invertebrates such as amphipods and harpacticoid copepods. In terms of nutrient exchange, eelgrass absorbs phosphorus through leaves and roots and returns phosphate to the water upon decomposition. The roots also take up nitrogen which is transferred by the leaves into the water. One of the most important functions of eelgrass meadows is based on its contributions to detritus and related detrital food webs. The detritus initiates sulphate reduction, maintaining an active sulphur cycle.

Eelgrass leaves also provide a substrate for the attachment of herring spawn. Herring were reported by Goodman (1975) at most stations over Sturgeon and Roberts Banks. Juvenile chinook caught on Roberts and Sturgeon Banks had been feeding primarily on larval and juvenile fish, especially herring (Goodman 1975). It is also believed that juvenile crabs utilize the eelgrass beds at Roberts Bank, but no data are presently available.

Effects of oil on salmon must be considered in addition to the habitat destruction caused by construction, dredging, erosion, landfilling and siltation. Oil may come from either a spill or from normal leakages and discharges which are likely to increase substantially with the predicted increase in ship traffic to and from the superport.

Adult pelagic fish are probably able to avoid oil contaminated areas (Straughan 1971), and adults may be able to avoid adherence of oil to their bodies by the external mucus coating (Nelson-Smith 1972). The most severe effects would be on the juvenile salmon. Juvenile coho and sockeye salmon showed signs of stress within 45 minutes after exposure to 500 ppm of



Prudhoe Bay crude oil and a subsequent loss of equilibrium within 24 hours (Morrow 1974). Avoidance reactions to 0.13 ppm to Prudhoe Bay crude oil occur in pink salmon fry (Rice 1973). Stress and avoidance reactions could also be expected to occur in even younger larval fish, such as herring, which as previously indicated are an important source of food to chinook salmon on Roberts Bank (Goodman 1975).

Obviously the effects of oil on salmon depend on many factors, including the type of oil, its concentration, environmental conditions, exposure time, species involved, and the life history stage (Albright et al 1977). The time of year at which toxic levels occur is also important, the most disastrous times presumably being when the fry are on Roberts Bank (i.e. spring and summer months).

Oil may also affect salmon through a food web. Chemo-reception of some littoral animals may be inhibited by low concentrations of oil in the water. Many marine animals use chemo-reception for mating, feeding and navigation. Any interference can lead to changes in the species distribution and abundance, and species composition. Examples of organisms in which such interference occurs are crabs (Takahashi and Kittredge 1973), snails (Jacobson and Boylan 1973) and bacteria (Mitchell et al 1972).

In summary, Roberts Bank port expansion would have many detrimental effects on salmon, directly through habitat destruction or degradation, and indirectly through increases in ship traffic. Port expansion would jeopardize investments in the Salmon Enhancement Program in B.C., which has a budget of \$20 million for 1978-79 alone, and an estimated total cost of \$400 million (1977). It would jeopardize investments in the B.C. salmon fishing industry. The gross annual value of the Fraser River salmon catch at retail is approximately \$86 million expressed in 1976 dollars. Assuming that the real value of salmon as food will increase at 2.7% per year and discounting future values at 6%, the present value of this catch, over 70 years, will approximate \$2.5 billion. If production increases associated



with the Salmonid Enhancement Program are also included, the present value of future salmon catches, over 70 years, are estimated to exceed \$3.4 billion. (These and other estimates in this paragraph are taken directly from the report of the Habitat Working Group of the Fraser Estuary Study.) Residents of the entire Fraser River drainage basin placed an annual recreational activity value of \$90 million on the River's salmon and steelhead. This value, if extended over the next 70 years, is estimated to be \$6.3 billion in present terms. In addition, residents associated an additional \$111 million annually with preservation of Fraser salmon stocks. It is important to note that the salmon fishery represents a renewable resource for the whole country which, if managed properly, will be with us in perpetuity, unlike the non-renewable bulk commodities which would be trans-shipped at an expanded Roberts Bank superport. In a recent random sampling of households in Greater Vancouver and Prince George, ninety-nine percent of residents called for salmonid stocks to be protected or increased, with fifty-two percent calling for the strongest possible increase. Finally, Fraser River salmon have been interwoven into the subsistence and cultural patterns of Native People for centuries. (It must be remembered that of the five species of salmon returning to the Fraser River, chinook salmon is the species which predominantly utilizes Roberts Bank at the juvenile stage. The annual commercial catch of chinook salmon in the Fraser Estuary alone is 480,000 fish, which represented a value of \$3.7 million in 1969, and this does not include the Fraser River chinook which were caught in Georgia Strait or the North Pacific Ocean. (Comparable figures for sport fish catches or Indian food fishery catches of chinook on the Fraser River are not available.) This figure, although modest when compared to the overall figures, still represents a very large commercial value when viewed from a long-term perspective.)

WATERFOWL

The mudflats of Sturgeon Bank, Roberts Bank and Boundary Bay are the largest wintering grounds of waterfowl in B.C.. Aquatic birds on the flats feed primarily on invertebrates and/or fish (Northcote 1974). Five species of waterfowl (mallard, pintail, American widgeon, greater scaup, and green-winged teal) eat plant material on Roberts and Sturgeon Banks. Surf scoters, black scoters, white-winged scoters, oldsquaw and common goldeneye consume mainly animal matter. Surf scoters eat primarily *Mytilus edulis*, white-winged scoters and oldsquaw eat primarily clams, and common goldeneye eat primarily crabs and shrimp. Scaup and scoters seem to prefer wintering in Boundary Bay and thus are not as important in the Roberts Bank area as other species of waterfowl. However, the combined numbers of mallard, pintail, American widgeon and green-winged teal occurring in the Fraser Delta intertidal area average 45-60,000 from October through December (1966-1975 figures). These figures can be misleading because maximum numbers are in the order of 130-200,000 for the same months, which indicates considerably more usage at certain times (Vermeer and Levings 1977).

The three areas of mudflats total 20,000 hectares, with Roberts Bank accounting for 8000 hectares, Sturgeon Bank 6000 hectares, and Boundary Bay 6000 hectares. Since mallard, pintail, American widgeon and green-winged teal utilize Roberts and Sturgeon Banks predominantly, on the basis of existing information it could be stated that 60% of the total populations of these species utilize Roberts Bank alone. This represents 27-36,000 birds in combined numbers (October through December) with estimated maximum numbers from 78-120,000.

The lesser snow goose is the most common goose wintering on Roberts and Sturgeon Banks, in numbers ranging from 8000-11,000 from October through April (Vermeer and Levings 1977). In addition, the Christmas Bird Counts of the Vancouver Natural History Society (1971 and 1972) indicate that the White Rock

area has large numbers of glaucous-winged gulls (785 and 1178), mew gulls (91 and 1564) and common murrelets (372), all of which may be feeding at some time on Roberts Bank. Several bald eagles were also sighted (2 and 6). Other aquatic birds and waterfowl occurring in the flats in the thousands are western grebes, dunlin and western sandpipers (Vermeer and Levings 1977).

The waterfowl which stand to lose the most from habitat destruction due to port expansion would be mallards, pintail, American widgeon and green-winged teal, primarily because they feed on the vascular plants (especially eelgrass) growing on Roberts Bank. They would be most vulnerable during peak usage which occurs in December when there are estimated maximum numbers of 120,000 birds of these species on Roberts Bank alone, and 200,000 on the whole Estuary intertidal area. However, all of the aquatic birds would suffer to some degree because they all use Roberts Bank to some degree. If key feeding areas on Roberts Bank such as those in the vicinity of the superport were destroyed or were unavailable then bird mortality for all of the species mentioned would certainly increase.

In addition to the habitat destruction which the construction of the port expansion would entail, there is again the added danger of an oil spill, or additional oil in the water which would come from the normal operations of the increased freighter traffic in the area. Sea ducks would be more vulnerable to oil spills than would seagulls, fulmars, and other aerial and land birds (de Ridder 1961). Some ducks are actually attracted to oil slicks, which they probably mistake for calm water or fish shoals (Curry-Lindahl 1960).

Decreases in estuary bird populations have been correlated with heavy oil pollution and emulsifier treatment, mainly due to damages to the food supply (Buck and Harrison 1967). Most affected were intertidal and plant feeders; fish-eaters were least affected. Permanent deposits of oil on beaches and on the bottom of shallow water also reduce the food supply (Ericson 1962). One disaster to waterfowl has already occurred in Canada when an oil spill in the St. Lawrence covered marsh grass utilized by wintering snow geese. Many birds were saved because the oily grass was removed, but they would have died if the

spill had occurred a few weeks later when the majority of the birds would have arrived (Eagles 1964).

Oil leaks from freighter traffic could affect the breeding success of many other aquatic birds on islands off the coast of B.C. (primarily the Gulf Islands) who do not directly utilize the Roberts Bank habitat. Adult birds which are lightly contaminated with oil would incubate, thus covering the eggs with a thin film of oil (Albright et al 1977). This prevents the eggs from hatching and causes the adults to incubate for exaggerated periods of time (Rittinghaus 1956, Jouanin 1967). Only 21% of duck eggs hatch when they are lightly coated with oil (Hartung 1965). The thin film of oil prevents the unhatched chicks from breathing through the egg shell, and they thus suffocate. Oil is so effective in reducing hatching success that it has been used to control populations of gulls and cormorants: 90% of the eggs do not hatch (Gross 1950).

A point system has been devised by King and Sanger (1977) to score the vulnerability of individual species of aquatic birds to oil pollution. Of the aquatic bird species breeding off the coast of B.C., the following were found to be vulnerable to oil (scale of 1-100, over 50 indicates over-vulnerability): fork-tailed petrel (67), leach petrel (63), common murre (70), pelagic cormorant (63), pigeon guillemot (82), marbled murrelet (84), ancient murrelet (74), cassin auklet (84), rhinoceros auklet (74), and tufted puffin (72).

The construction and presence of port expansion on Roberts Bank could therefore have severe effects on aquatic birds. Not only would prime habitat used extensively by overwintering flocks be destroyed, but there would further be reduced breeding success of aquatic birds in Georgia Strait. Most of these birds have low intrinsic rates of natural increase because of small clutch sizes (only one or two eggs at a time, once every one or two years) and would take a long time to recover from breeding losses (Albright et al 1977). An oil spill in either case (either during winter when there are overwintering flocks or in spring and summer during incubation) would probably be disastrous. It must

be stressed that a spill of oil used as fuel by freighters would be large enough to cause a major environmental disaster. (That is, it is mistaken to believe that very large quantities of oil, such as from a tanker spill, are required to produce a major catastrophe to the ecology of a restricted area such as Georgia Strait. Relatively small quantities of oil tend to spread in a thin film over a large area of water surface.) Apart from an actual spill, routine oil emissions from freighters would increase the environmental oil hazard to aquatic birds in Georgia Strait.

BENTHIC ORGANISMS

As of 1972 the meiofauna community in the Fraser Estuary showed no signs of eutrophication (Bawden et al 1973). Except in the areas of sewage outfall there did not as yet appear to be any adverse signs of pollution. Three major groups of meiofauna occur on Roberts and Sturgeon Banks: nematodes ($0.5-55/\text{cm}^{-2}$), oligochaetes ($0.2-37/\text{cm}^{-2}$), and copepods ($2-33/\text{cm}^{-2}$). The macrofauna of the fine-grained sediments mainly included the mollusk Cryptomya californica, and the polychaete Hemipodus borealis. In the coarse-grained sediments the crustacean Callianassa californiensis was more common.

Many of the benthic macrofauna are eaten by diving ducks. These macrofauna include bivalves, snails, crustaceans, and polychaetes. Their larval forms, which are part of the meroplankton, are also important as food for fish, including juvenile salmon. The main damage done to these organisms by an expansion of the port facilities at Roberts Bank would be by oil leakages and spills from the increased freighter traffic serving the ports.

The fertilization of eggs, embryonic and larval development, are the most

susceptible stages in the life history of bivalves (Renzone 1973). The percentage of eggs fertilized by sperm is reduced when the sperm are exposed to oil (84% when exposed to 0.1 ml oil/1 water, and 71% at 1.0 ml/1)(Renzone 1973). Low concentrations of oil also inhibit chemo-reception which is used by many larval forms for feeding and navigation (Albright et al 1977). Thus, very low concentrations of oil can be disastrous to the benthic ecology.

Oil may also affect the adult bivalves themselves, those living in sand more so than those on hard substrates (Woodin et al 1975). Oil easily incorporates into the sediments (Ruttler and Sterrer 1970), and has a half-life as long as 15 years (Ruttler et al 1973). Petroleum hydrocarbons are readily accumulated by bivalves (Stegeman 1974). Such accumulations are known to selectively alter enzyme activity in the oyster Crassostera virginica (Heitz et al 1974), and may affect other bivalves as well. The behaviour of bivalves may also be altered by the soluble fraction of oil. For example, there may be no attachment of byssal threads (Linden 1977), and respiration may be decreased (Dunning and Major 1974).

Oil pollution by freighters may affect the macrofauna indirectly by killing plankton. Phytoplankton can recover from oil spills very quickly, but the species composition may change (Pulich et al 1977). This change in species composition in phytoplankton can change the species composition of primary consumers in the benthos, especially since many are selective in their grazing, or digest some foods better than others (Fisher and Wurster 1974).

Many benthic organisms will be killed directly during the construction of additional port facilities at Roberts Bank. The area involved would probably be relatively small, but more importantly the habitat in this area will be altered, i.e. the sediment characteristics may change. This will initiate a change in the species composition and abundance of benthic organisms, and extend over a wider area. This would affect organisms higher up in the food chains involved, namely salmon and waterfowl.

CRABS

Crabs are an important source of food for many aquatic organisms. The larvae of crabs are eaten by fish, including young salmon and herring. Adult crabs are eaten by octopus, which in turn are important in the diet of ling cod, and to some extent coho salmon, flounder and halibut. Crabs also help consume dead fish and other organic matter, and in this way are involved in the recycling of nutrients.

In addition to the role of crabs in food webs of fish exploited by man, crabs are also harvested directly. The Fraser Estuary accounts for 10% of the crab industry in B.C.. The 1976 commercial crab fishery on the Fraser Estuary produced 934,000 pounds of crab (approximately 43% of the total B.C. catch) valued at approximately \$1.5 million (Fisheries and Environment Canada 1976). Considerable numbers of Dungeness crab are caught on the outer edges of Roberts Bank.

There is some danger to crabs by the proposed port expansion at Roberts Bank, mainly because of increases in the volume of coal. Before the development of the present coal facility at Roberts Bank there was no coal present in the marine sediments. Since Westshore Terminals Ltd. began operations the amount of coal dust in the marine sediments has been slowly accumulating, especially to the northeast and east where it accounted for more than 2.5% of the non-hydrolyzable solids of the sediments in July 1975 (Pearce and McBride 1977). Accumulations of 1-2.5% of coal in the sediments occurred at least 400 m in all directions from the facility, and 750 m to the north.

Coal particles tend to accumulate in the gill lamellae of crabs, the amount being positively related to the concentration of coal in the sediments. Pearce and McBride (1977) failed to demonstrate any histo-pathological changes in the gill lamellae of the dungeness crab (Cancer magister), after 22 days of exposure to a substrate containing 50% coal and 50% sand. However, long-term adverse effects may still occur.

These long-term effects need not be physiological as Pearce and McBride investigated. During their experiments they noted a marked behavioural change in crabs due to the presence of coal in the substrate. Crabs only burrowed in substrates containing coal (Substrates tested were 25% and 50% coal). The authors offered no explanation for this change in behaviour, and did not speculate as to its possible consequences. But, it may be important to the survival and fecundity of the crabs on Roberts Bank. Increased handling of coal may extend the area of coal accumulation in the sediments, increase the concentrations, and thus perhaps reduce crab populations.

Oil would also have very definite effects on crabs. Chemo-reception, which is used for mating, feeding and navigation by crabs, may be inhibited by low concentrations of oil in the water. Any interference can lead to changes in the species distribution and abundance and species composition. (Takahashi and Kittredge 1973).

Many crabs will also be directly destroyed by the construction of Roberts Bank port expansion. Damage to the resident population will be most severe if construction and dredging occurred during late spring when there would be large numbers of larvae in the water. A decrease in the number of larvae in the meroplankton could have food chain effects on salmon and herring in the area, and probably would have effects later on wintering waterfowl such as scoters and goldeneyes which feed on adult crabs.



CONCLUSIONS

An expansion of the port facilities at Roberts Bank can have disastrous effects on the ecology of salmon and other fish such as herring, waterfowl, benthic organisms, and crabs in the area.

The possible effects of the construction and operation of the facilities cannot be accurately predicted from available information. If at all possible more research should be done by qualified scientists to determine what the destruction of the flora and fauna will be, before any construction begins. No more public monies should be spent on literature summaries and haphazard research done by unqualified individuals.

We do know that Roberts Bank port expansion will have definite effects on salmon, herring, waterfowl, crabs, and benthic organisms in the area, both directly through physical removal of vegetation upon which these animals feed and indirectly through food chains based on this habitat. We also know that oil has definite effects on fish, waterfowl, benthic organisms and crabs, both directly in terms of mortality and interference with physiological processes, and indirectly through food chains. The question of oil pollution is especially relevant because of the projected increase in freighter visits to Roberts Bank from 125 to 700 per year. The effects of routine oil discharges alone from these ships could prove to be disastrous to marine habitat areas throughout the lower Georgia Strait.

The port facilities should not be built unless they can be planned with a large margin of safety for the flora and fauna; large because the Roberts Bank area may become very important in the future to the ecology of the Fraser River Estuary. Safety margins should be calculated with the knowledge that the use of Roberts Bank by marine flora and fauna will almost certainly increase in the next few decades. This margin of safety cannot be calculated unless precise knowledge of the impacts is available. At present we still do not have such knowledge.

BIBLIOGRAPHY

- *Albright, L., J. Chocair, J. Kiss, P. Lauzon, R. Lauzier, D. Mahon, R. Murray, E. Peitso, D. Popham, and M. Valdes. 1977. The influence of oil spills upon various marine micro- and macro-organisms of Canada's west coast. West Coast Oil Ports Inquiry Report. 72 pp.
- *Bawden, C.A., W.A. Heath, and A.B. Norton. 1973. A preliminary baseline study of Roberts and Sturgeon Banks. Westwater Research Centre Tech. Rep. No. 1. 54 pp.
- Blumer, M., G. Souza, and J. Sars. 1970. *Mar. Biol.* 5:195-202.
- Buck, W.F.A., and J.G. Harrison. 1967. The Wildfowlers' Association of Great Britain and Ireland. Annual Report and Yearbook 1966-1967:32-33.
- Curry-Lindahl, K. 1960. *International Waterfowl Res. Bureau Newsletter* 10:15-18.
- De Ridder, M. 1961. *Les Naturalistes Belges* 42:145-56 (Eng. Trans. available as Can. Wildlife Service TR-FR-32).
- *Dorcey, A.H.J., T.G. Northcote, and D.V. Ward. 1978. "Are the Fraser marshes essential to salmon?" Westwater Lectures No. 1. Westwater Research Centre. Univ. of B.C., Vancouver. 29 pp.
- Dunning, A., and C.W. Major. 1974. in: *Pollution and physiology of marine organisms:349-66.* ed. by F.J. Vernberg and W.B. Vernberg. Academic Press. N.Y.
- Eagles, D. 1964. *Can. Audubon* 26(2):37-39.
- Ericson, R.C. 1962. *Trans. of the Seminar on Biological Problems of Water Pollution* 3:177-181.
- Fisher, N.S., and C.F. Wurster. 1974. *Environ. Conservation* 1:189-90.

* primary reference

- Goodman, D. 1975. A synthesis of the impacts of proposed expansion of the Vancouver International Airport and other developments on the fisheries resources of the Fraser River estuary. Fisheries and Marine Service, Preliminary Draft Report. 137 pp.
- Gross, A.C. 1950. Proc. Xth International Congress of Ornithologists: 532-536.
- Hartung, R. 1965. J. Wildl. Mgt. 29(4):872-4.
- Heitz, J.R., L. Lewis, J. Chambers, and J.D. Yarbogh. 1974. in: Pollution and Physiology of Marine Organisms:311-27. ed. by F.J. Vernberg and W.B. Vernberg. Academic Press. N.Y.
- Jacobson, S.M., and D.B. Baylon. 1973. Nature 241:213-15.
- King, J.G., and G.H. Sanger. 1977. An oil vulnerability index for marine-oriented birds (in press). 25 pp.
- Linden, 1977.
- Mitchell, R., S. Fogel, and I. Chet. 1972. Water Res. 6:1137-40.
- Morrow, J.E. 1974. Effects of crude oil and some of its components on young coho and sockeye salmon. U.S. Environ. Prot. Agency No. EPA-660/3-73-018. 36 pp.
- Nelson-Smith, A. 1972. Oil pollution and marine ecology. Elek Science. London. 260 pp.
- * Northcote, T.G. 1974. Biology of the Lower Fraeer River: A Review. Westwater Research Centre Tech. Rep. No. 3. 94 pp.
- * Pearce, B.C., and J. McBride. 1977. A preliminary study on the occurrence of coal dust on Roberts Bank sediments and the effect of coal dust on selected fauna. Fisheries and Environment Canada Tech. Rep. Series No. PAC/T-77-17.
- Pulich, W.M., K. Winters, and C. Van Bales. 1977. Mar. Biol. 28:87-94.
- Renzoni, A. 1976. Mar. Pollut. Bull. 6:125-28.
- Renzoni, A. 1973. Mar. Pollut. Bull. 4:9.

- Rice, S.D. 1973. Toxicity and avoidance tests in the Prudhoe Bay oil and pink salmon fry. in: Proc. of Joint Conf. on Prev. and Control of Oil Spills. Amer. Petrol. Inst. pp. 667-70.
- Rittinghaus, H. 1956. Ornithologische Mitteilungen 8(3):43-46. (Eng. Trans. available as Can. Wildlife Ser. TR-GER-98).
- Ruttler, K., and W. Stirrer. 1970. Bioscience 20:222-24.
- Sibert, J., T.J. Brown, M.C. Healey, and B.A. Kask. 1977. Detritus-based food webs: exploitation by juvenile chum salmon (Oncorhynchus keta). Science 196:649-50.
- Straughan, D. 1971. Biological and oceanographic survey of the Santa Barbara oil spill, 1969-1970. vol. 1.- Biology and Bacteriology. Univ. of S. Calif. 426 pp.
- Stegeman, J.J. 1974. in: Pollution and Physiology of Marine Organisms:329-47. ed. by F.J. Vernberg and W.B. Vernberg. Academic Press, N.Y.
- Takahashi, F.T., and J.S. Kettredges. 1973. Sublethal effects of the water-soluble components of oil: chemical communication in the marine environment. in: The Microbial Degradation of Oil Pollutants:359-64. ed. by D.G. Ahearn and S.P. Meyers.
- * Vermeer, K., and C.D. Levings. 1977. Populations, biomass, and food habits of ducks on the Fraser Delta intertidal area, British Columbia. *Wildfowl* 28:49-60.
- Woodin, S.A., C.F. Nyblade, and F.S. Chia. 1975. Mar. Pollut. Bull. 6: 139-42.