Restoration notebook

September 1998

Exxon Valdez Oil Spill Trustee Council

Photo by Mark Carls

Pacific Herring

Clupea Pallasi

By Evelyn D. Brown, University of Alaska Fairbanks, and
Mark G. Carls, National Marine Fisheries Service, NOAA

Few species are of greater combined ecological and economic importance in Prince William Sound (and in many other coastal ecosystems) than is the Pacific herring, *Clupea pallasi*. Herring of all life stages are central to a marine food web that includes humpback whales, harbor seals, a large variety of marine and shore birds, bald eagles, jellyfish and other invertebrates, and an array of other fishes, such as pollock. In addition, herring—especially their eggs—provide a multi-million dollar resource that is available to commercial fishers in the spring, before the main salmon seasons open.

Pacific herring belong to the family Clupeidae, which includes small fish that occur in enormous numbers in large schools. Pacific herring range from Baja California, Mexico north to the Beaufort Sea and south along the coast of Asia to Korea.[1] They inhabit continental shelf regions and spend much of their lives in nearshore areas.[1,2] Herring are abundant within the area contaminated by the *Exxon Valdez* oil spill (EVOS), including in Prince William Sound (PWS), the outer Kenai Peninsula coast, lower Cook Inlet, and in the waters around the Kodiak Archipelago.

Herring are a bony, streamlined fish, about eight inches long, with very oily flesh. On their backs, they have distinctive blue-black shading, which brightens to silvery white on their sides.[1] Silvery layers of guanine crystals in their skin reflect light and serve as camouflage. Herring also have specialized retina in their eyes, allowing filter feeding in darkness, and very complex nerve receptors that link the lateral line with the swim bladder, allowing rapid vertical movements.[3]

Vital Statistics

Population
Approximately 34,100 metric tons in PWS (1997); 35,054 metric tons (1998 forecast)

Population Trend
Highly variable; Peaked at over 110,000 metric tons in 1989; Collapsed in 1993; Now slowly increasing (1998)

Lifespan
Up to 12 yrs in PWS

Adult Size
Varies with latitude. In PWS, adults are greater than 170 mm in length and 80 g in weight.

Spawning Season
Varies with latitude; April in PWS; Duration variable from 5 days to 2 or 3 weeks.

Incubation Period
Temperature dependent; About 24 days in PWS

Larval Period
About 10 wks; 30 mm larvae metamorphose to juvenile in July (PWS)

Maturity
Spawning is rare before age 3 in PWS

Diet
Larvae: invertebrate eggs, tiny zooplankton; Juveniles and adults: zooplankton, krill, and larval fish

They are fast swimmers with a burst swimming speed of 5-7 body lengths per second, which is as fast as many salmon.[4,5] The configuration of herring schools, their swim speed and agility, and the flashes of reflected light probably confuse predators.[3]

Spawning

In PWS, mature adult herring migrate to and then spawn in shallow waters mainly in April, although some spawning occurs in late March and as late as June. Eggs are deposited along many of the same beaches year after year, although the volume of eggs and the number of miles of shoreline along which spawning occurs vary widely.

Readiness to spawn appears to be related to winter and spring sea-surface temperatures.[6] In general, herring spawn when ocean currents are weak, reducing the chance that the tiny larvae will be swept off shore.[7] Specific spawn timing seems to be tied to temperature (4.4 degrees C in PWS) and calm seas. The timing and location of spawning herring is often signaled by the large, noisy flocks of gulls, waterfowl, and shorebirds, and groups of Stellar sea lions that gather to feed both on the herring and their eggs.

Female herring carry from 7,000 to 30,000 eggs,[6] depending on body weight (about 200 eggs per gram of fish weight[8]). Eggs are laid in multiple layers on kelp, rockweed, eelgrass, other seaweed, and rocks in the intertidal zone. About 90% of the eggs are deposited between -5 and +2 m mean lower low water.[9] After spawning, aggregations of adult herring thin out and retire to deeper waters, presumably close to the entrances of PWS to feed.[10] Little is known about summer distributions and habits of adult herring.

Temperature determines the incubation period for eggs. In PWS, eggs incubate for about 24 days[6] compared to only 14 days in British Columbia.[1] Egg loss due to wave action and predation can be up to 90 percent.[11,12,13] Of those that actually hatch, it is not uncommon to observe 50% or more with morphological abnormalities.[14,15]

Juvenile Herring

In PWS, larvae hatch from eggs in May, and they are about 7-9 mm long and carry a yolk-sac.[16] Newly hatched larvae are vulnerable to being swept away by currents[17] and predation by jellyfish, other invertebrates, and fish, such as pollock.[1,14] The yolk-sac reserves are used up in about one week, depending on temperature. Without additional food, starvation is irreversible within about 10 days.[18] Larvae eat a variety of zooplankton and are found in mid-waters of PWS throughout the summer.[19] Metamorphosis to adult form occurs after about 10 weeks, when the larvae are about 30 mm in length.[1]

Nearshore habitats appear to be important for juvenile herring for at least the first year of life.[10,20,1] More than 90% of the juveniles in British Columbia[21] and PWS[22] were within 2 km of shore, often in bays.

They may spend up to two years in these nearshore rearing areas[21] before joining the adult population. Overlap in distribution with juvenile pollock, which prey on juvenile herring, is significant. Juvenile herring also may be a critical food resource for foraging seabirds and marine mammals, because of their high energy (fat) content, abundance, and availability in surface waters.

In the fall, large aggregations of adult herring, mixed with 2-year-old herring, return from summer feeding areas and overwinter in central and eastern PWS. They concentrate in huge schools, which can be observed and measured with sonar, possibly providing a cost-effective means of assessing population sizes. Humpback whales have been seen as early as October and as late as February feeding on these large schools (e.g., 24 whales were observed around Montague Island in December 1996). Preliminary data[22] indicate that during the winter, age-0 and -1 her-

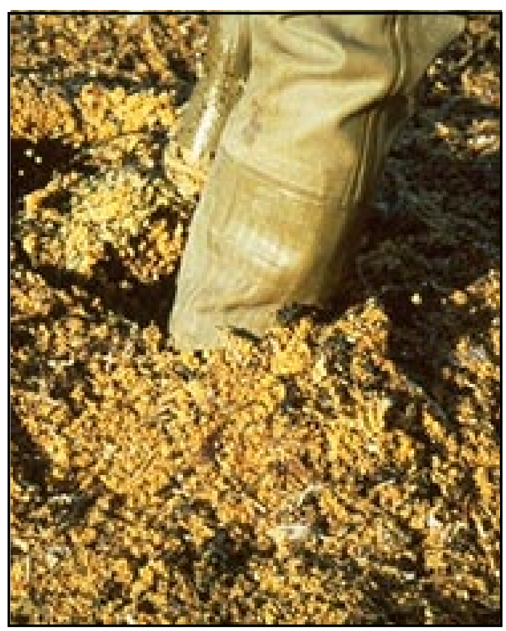
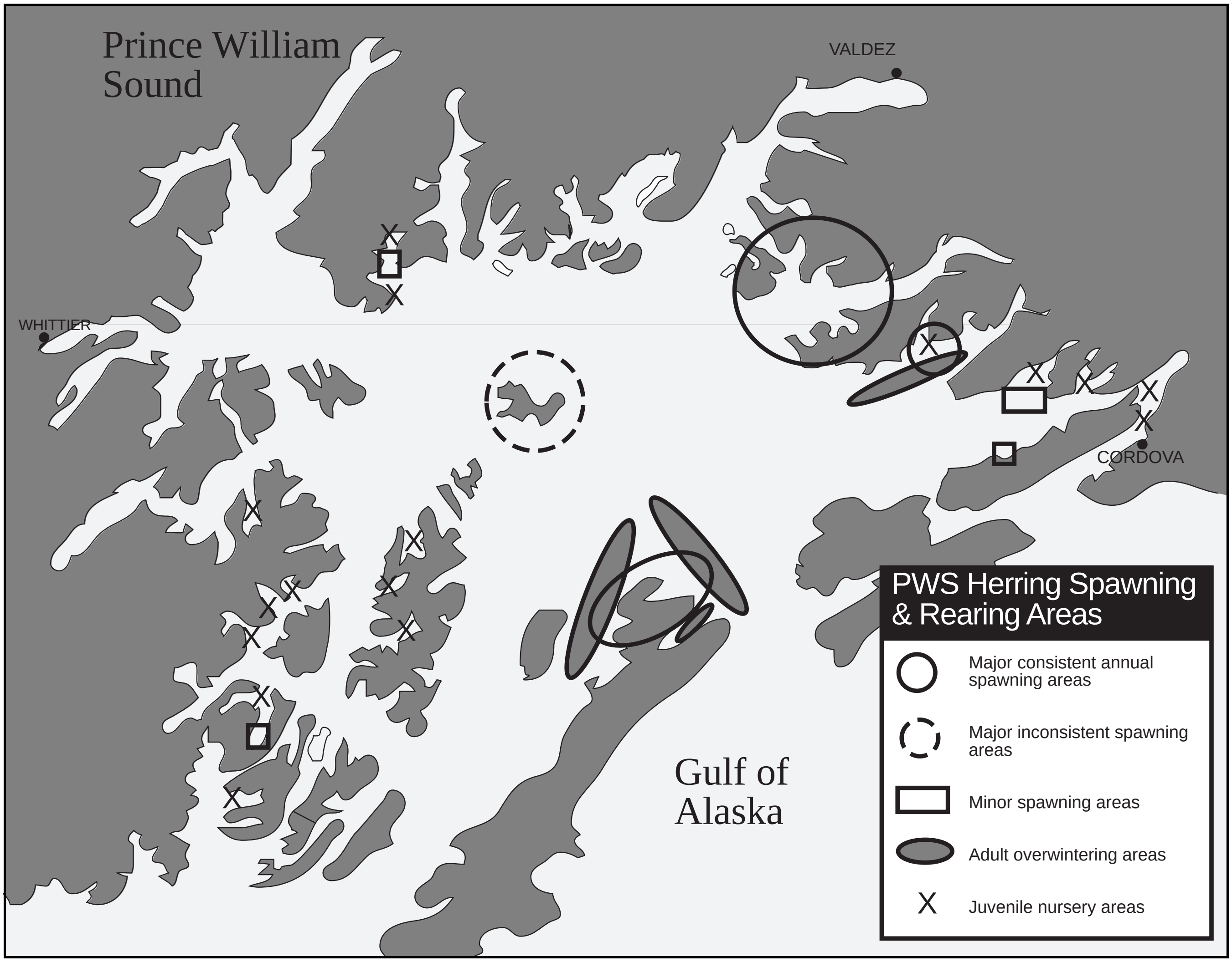


Photo by Stan Senner

Thick mats of herring spawn, attached to eelgrass, washes up on the shores of Prince William Sound.



ring remain in their nearshore nursery bays, overlapping in distribution to a small degree with the adults.

Population Status and Trends

Pacific herring populations vary tremendously due to natural causes, such as predation, larval drift, disease,[23] and starvation.[2] Herring also are vulnerable to fishing pressure[10,1] and to the direct and indirect effects of oil spills, such as the *Exxon Valdez* spill.[24] A strong year-class is recruited in PWS about once every four years; this cohort usually then dominates the population for the next four years.[25]

There have been large commercial fisheries on Pacific herring since the early 1900s, when they were first dry-salted for Oriental markets (1904-34). For the next 30 years (1935-67), herring were sold domestically and overseas, primarily for fish meal and oil. More recently, they have been harvested for their roe and spawn-on-kelp (both Oriental markets), food (mainly overseas), and bait (domestic).[1] Catches during the early years were not controlled, and fishermen took a large percentage of the population, which may have been severely reduced as a result.

Prior to the EVOS, the population in PWS was at a high level and increasing.[26] Estimates of the biomass of spawning adult herring since the 1980s range from a low of 16,400 metric tons in 1994 to a high of 113,200 metric tons in 1989 (John Wilcock and Fritz Funk, unpubl. data). The 1989 year class failed to join the spawning population in PWS in 1993, and only about 25% of the forecasted return of adults actually returned.[25] As a result of this dramatic population collapse, PWS herring fisheries were curtailed in 1993 and closed from 1994-1996. By 1997, the population in PWS was estimated to be about 34,000 metric tons, and a limited commercial

Photos on right: Herring larvae show adverse effects from exposure to oil with malformaties becoming more pronounced as oil exposure increases.

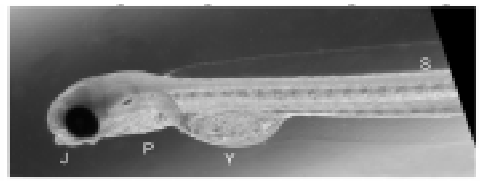
harvest was allowed. The 1998 season resulted in harvests of 3,443 tons for sac roe, 356 tons for gillnet sac roe, and 679.7 tons from the food and bait fishery (harvested in the fall of 1997).

Short-term effects of the spill

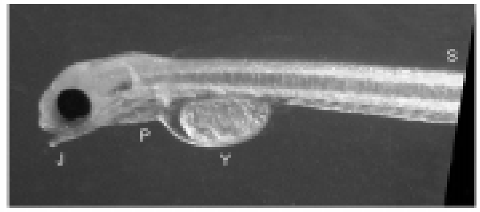
The *Exxon Valdez* oil spill occurred on March 24, 1989, a few weeks before herring spawned in PWS. Because many herring were gathering in oiled waters to spawn, all herring fisheries were closed in 1989 to eliminate the risk of contaminated catches. About half of the egg biomass was deposited within the trajectory of the spilled oil, and an estimated 40% to 50% was exposed to oil during early development.[24] An unknown proportion of oil was dispersed throughout the water column to a depth of at least 25 m.[27] Oil was in the water throughout the summer of 1989 and, to a lesser degree, in 1990, following beach cleaning operations.[27]

Adult herring also were exposed to spilled oil, but the effects of this exposure are not clear. Adults sampled immediately after the spill at oiled sites had liver lesions that were attributed to oil exposure.[28] Recent laboratory studies have shown that exposure of wild herring to concentrations of crude oil similar to those that may have been encountered in PWS following EVOS depressed immune functions and allowed expression of a viral disease, viral hemorrhagic septicemia (VHSV), which also is associated with lesions.[29] Thus, the lesions originally attributed solely to oil exposure in herring captured from PWS in 1989[28] may have been caused by disease, which, in turn, may have been triggered by oil exposure. This suggestion is further supported by occurrence of similar lesions in VHSV-positive herring sampled from PWS at the time of the population collapse (1993-1994), when hydrocarbon exposure was no longer detectable.[23,30]

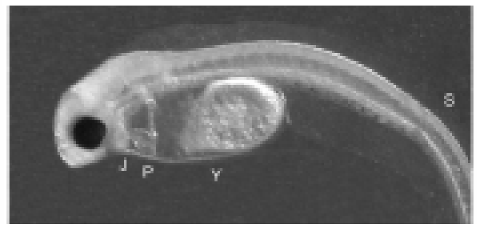
Physical abnormalities and genetic effects caused by exposure of herring eggs to oil include increases in the incidence and severity of various morphological malformations[31,32,33,34] and chromosomal aberrations.[35,36,37] Recent experimental research that modeled conditions observed in PWS have shown



Control: normal jaw, normal pericardium, normal yolk, straight spine.



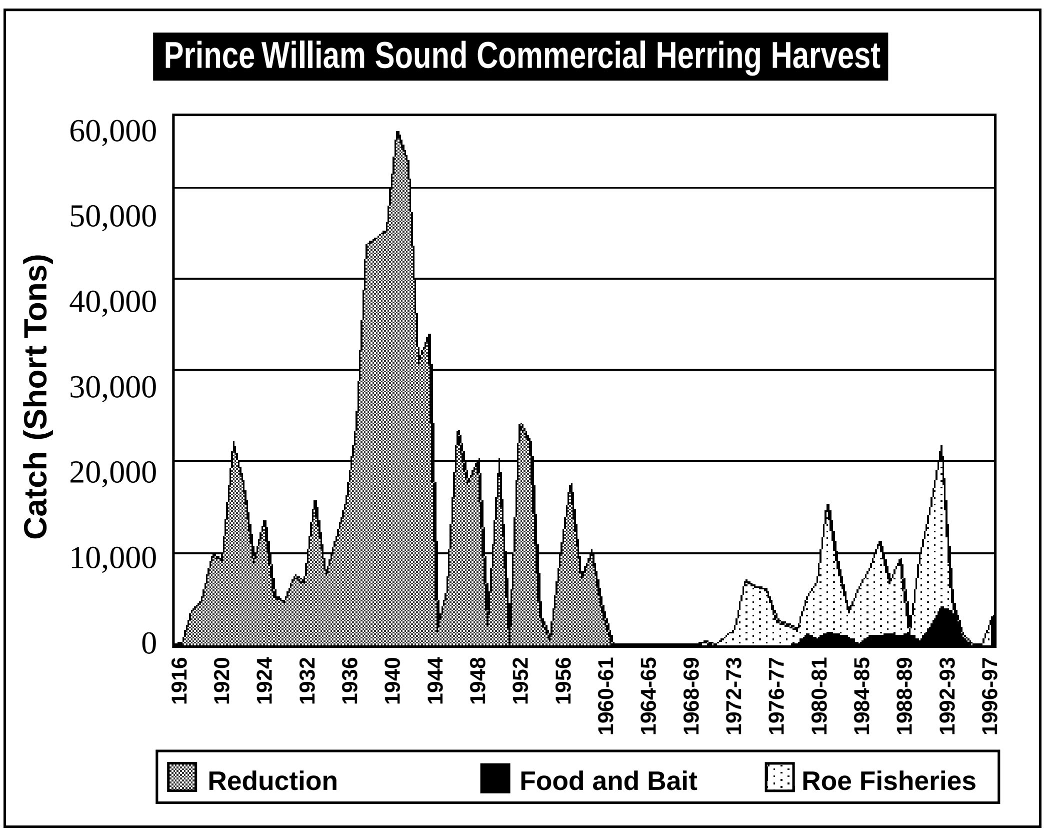
Low oil: normal jaw, normal pericardium, yolk edema, straight spine.



High oil: deformed jaw, pericardial edema, yolk edema, curved spine.

Photo by Dr. Jo Ellen Hose

Commercial harvest of Pacific herring in Prince Willam Sound, all fisheries 1917-1997.



biologically significant sublethal effects and mortality consistently occur after exposure to waterborne polynuclear aromatic hydrocarbons (PAHs) in the low parts-per-billion range (0.2 to 9 ppb).[38] The morphological and genetic effects observed by Carls[38] were identical to those observed in herring larvae of different ages from oiled areas within PWS during spring 1989.[24,15,19]

Photo by Roy Corral

Herring are sampled as part of a study examining their availability and importance as a food source for seabirds.

Early life stages of the 1989 year class in PWS were affected by *Exxon Valdez* oil. Primary effects included: premature hatching, low larval weights, reduced growth, elevation in morphologic and genetic abnormalities, and, probably, mortality.[39] Although we do not know the level of mortality, research suggests that there was a significant reduction (52%) in larval production in 1989.[40,24] While approximately equal biomasses of eggs were deposited in unoiled and oiled areas, it is estimated that oiled areas produced only 17 million viable pelagic larvae compared to 12 billion from unoiled areas.[39]

Ingestion of oil-contaminated food by larvae and juveniles may have been a significant route for oil exposure because copepods, one of the major prey items for young herring, accumulate and concentrate petroleum hydrocarbons in their bodies.[41,42] Contact with particulate oil and exposure to dissolved PAH also were possible, but many of the abnormalities observed in larvae in oiled areas[19,15] may have been caused by earlier exposure of incubating eggs. Juvenile herring were not studied immediately after the spill, but growth of juvenile pink salmon (which occupied the same intertidal habitat) was reduced in oiled areas.[44,45] Researchers concluded that ingestion of whole oil was an important route of contamination, but did not exclude other possible avenues of exposure such as direct contact with sheens.[43,46,49]

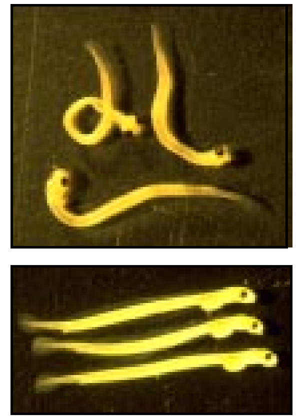


Photo by Richard Kocan

Normal, viable herring larvae have straight spines whereas abnormal, non-viable larvae are easily identified by the curvature in their spines.

Long-term effects of the spill

Natural variability in herring populations is poorly understood. Thus, despite the estimated substantial decrease in larval production in 1989, oil exposure cannot be singled out as the cause for the 1993 recruitment failure. The 1989 year class was one of the smallest cohorts ever observed returning to spawn in PWS, and it made up only a small proportion of the overall 1993 spawning population. The VHSV disease also plagued the returning adult population in 1993.[23] Possible causes of this disease-precipitated collapse include high population density, food scarcity, poor ocean conditions, and previous (i.e., in 1989) exposure to oil.[24,39,33]

One area of concern was the possibility that herring genetically damaged by exposure to *Exxon Valdez* oil would perpetuate abnormalities in the gene pool. There is no strong evidence, however, of long-term reproductive impairment. In laboratory tests, morphological abnormalities coincided with genetic abnormalities, but genetically damaged larvae would probably die before metamorphosis.[38] Similarly, declines over time in the incidence of abnormal larvae in PWS[19] can be explained by the death of affected larvae. A preliminary study in PWS in 1992 that compared reproductive success between two previously oiled sites within Rocky Bay and one unoiled site at Tatitlek Narrows suggested a possible long-term oil effect, but other factors may have been confounding.[47] In 1995, a similar study involving multiple control and oiled sites in PWS, plus control sites in Southeast Alaska, found no evidence of long-term, oil-related reproductive impairment in PWS.[48]

Although there is no evidence of long-term reproductive impairment due to EVOS, it is possible that the 1993 population collapse in PWS allowed other species of fish to take over the ecological niche once occupied by herring, thus


Photo by Roy Corral

Pacific Herring

slowing or reducing the likelihood of a population rebound. For example, pollock have apparently increased in abundance, and the resulting additional competition for food or predation pressure on all life stages of herring may help keep the herring population at a low level.

Restoration Activities

Starting with the Natural Resources Damage Assessment, which was initiated in the immediate aftermath of the oil spill, the *Exxon Valdez* Oil Spill Trustee Council provided funds for the Alaska Department of Fish and Game to improve its annual assessment of the biomass of spawning adult herring and the eggs they deposit in PWS. Then, following the collapse of the PWS herring population in 1993, the Trustee Council adopted a two-pronged approach. First, a team of researchers focused on disease as an agent of the collapse and possible links between oil exposure and disease. Second, the Trustee Council sponsored a large-scale study, the Sound Ecosystem Assessment (SEA), to identify the ecological processes influencing the survival of juvenile herring and pink salmon.

The disease work sponsored by the Trustee Council is providing insight into the possible causes of the 1993 collapse, but is also providing fisheries managers with important information about background levels of VHSV and the Icthyophonus fungus and the conditions which favor the expression of these diseases. Current research is looking at the possible relationship, if any, between disease epidemics and the practice of gathering large numbers of spawning herring into small enclosures, such as in the "pound" fishery.

The herring components of the SEA project are focusing on overwinter survival and summer habitats of juveniles. Models are being developed that describe how young herring are recruited into the adult population.[22] As part of this project, researchers are interviewing commercial fishers and others with local and traditional knowledge about herring to identify areas and habitat types where herring are consistently found. This information will help set priorities for habitat conservation.

Preliminary analyses from the SEA project suggest that mortality in the larval and juvenile life stages, not the embryo stage, has the greatest effect on the number of fish surviving to become adults.

Although billions of eggs hatch, few survive to metamorphosis, and larvae are difficult and expensive to study. The focus of the SEA project, therefore, is on the surviving juveniles, beginning in late summer when they first arrive at the nursery areas.

Habitat conditions, including food availability, the abundance of predators or competitors, and ocean conditions, dictate how young herring survive, grow, and store fat in preparation for winter. Age-0 herring must acquire enough oil reserves by fall to survive a winter when food is scarce. Winter survival, therefore, is likely to be critical to the successful recruitment of a year class relative to age, size and sex.[50]

Research and modeling will vastly improve our understanding of juvenile herring distributions, the processes affecting their survival, their availability to predators, and recruitment into the adult population. Researchers within the Alaska Predator Ecosystem Experiment (APEX) project, a study linking the availability of forage fish to the productivity of spill-injured seabird species, have found that juvenile herring are a key forage species in PWS, thus confirming the ecological importance of this species.

A monitoring plan is being developed that could track distribution and relative abundance of juveniles via aerial and acoustic surveys. These surveys could record yearly changes in populations, plus environmental variables, such as temperature and food availability, within representative nursery areas. Model simulations using this information should help improve stock assessments and forecasting and could prevent overfishing. With more research and careful management, the Pacific herring will remain a key member of the coastal ecosystem in PWS and throughout the northern Gulf of Alaska.

Fisheries biologist Evelyn Brown received an MS in fisheries from Oregon State University in 1980 where she worked on Pacific crayfish and aquaculture. She worked for ADFG for over 10 years and, after the spill, was the principal investigator for herring damage assessment studies for 5 years. She is currently a research associate at University of Alaska Fairbanks and working on her PhD concerning the distribution and ecology of herring and other forage fish species.

Fishery biologist Mark Carls received an MSC in biological oceanography in 1978 from Dalhousie University, Nova Scotia, where he studied the effects of oil exposure on Atlantic cod and mackerel. He continues oil research at the Auke Bay Laboratory, National Marine Fisheries Service in Juneau

From the air, schools of herring appear as dark pools within an otherwise clear Prince William Sound bay. At left, two schools of herring can be seen.

References

1. Hourston, A.S, and C.W. Haegele. 1980. Herring on *Canadaís* Pacific coast. Canadian Special Publication of Fisheries and Aquatic Sciences 48. Dept. Fisheries and Oceans, Ottawa. 23 pp.

2. Stocker, M. 1993. Recent management of the British Columbia herring fishery, p. 267-293. In L.S. Parsons and W.H. Lear [eds.] Perspectives on Canadian marine fisheries management. Can.Bull.Fish.Aquat.Sci. 226.

3. Blaxter, J.H.S. 1985. The herring: a successful species? Can. J. Fish. Aquat. Sci. 42(Suppl. 1): 21-30.

4. Salo, E. O. 1991. Life history of chum salmon. Pages 233-309 in Groot, C., and L. Margolis (eds), Pacific salmon life histories. UBC Press, University of British Columbia, Vancouver, Canada

5. Sandercock, F. K. 1991. Life history of coho salmon. Pages 397-445 in Groot, C., and L. Margolis (eds), Pacific salmon life histories. UBC Press, University of British Columbia, Vancouver, Canada

6. Biggs, E.D. and T.T. Baker. 1993. Studies on Pacific herring Clupea pallasi spawning in Prince William Sound following the 1989 Exxon Valdez oil spill, 1989-1992. Draft Report for Natural Resource Damage Assessment Fish/Shellfish Study Number 11, EVOS Trustee Council, Anchorage, Alaska.

7. Lasker, R. 1985. What limits clupeoid production? Can. J. Fish. Aquat. Sci. 42: 31-37.

8. Hay, D.E. 1985. Reproductive biology of Pacific herring (*Clupea harengus pallasi*). Can. J. Fish. Aquat. Sci. 42(Suppl. 1): 111-126.

9. Haegele, C.W., R.D. Humphreys, and A.S. Hourston. 1981. Distribution of eggs by depth and vegetation type in Pacific herring (*Clupea harengus pallasi*) spawnings in southern British Columbia. Can. J. Fish. Aquat. Sci. 38: 381-386.

10. Rounsefell, G.A and E.H. Dahlgren. 1931. Fluctuations in the supply of herring (*Clupea Pallasii*) in Prince William Sound, Alaska. U.S. Dept. of Commerce, Bureau of Fisheries Doc. No. 9: 263-291.

11. Palsson, W.A. 1984. Egg mortality upon natrual and artificial substrata within Washington State spawning grounds of Pacific herring (*Clupea harengus pallasi*). Maters Thesis, University of Washington, Seattle, WA. 191 pp.

12. Haegele, C.W. 1993. Seabird predation of Pacific herring, *Clupea pallasi*, spawn in British Columbia. Canadian Field-Naturalist 107(1): 73-82.

13. Rooper, C.N., L.J. Halsorson, and T.J. Quinn II. 1996. Physical and biological factors affecting Pacific herring egg loss in Prince Willam Sound, Alaska. Masters Thesis, University of Alaska Fairbanks, Juneau and Report to Alaska Department of Fish and Game, Cordova, AK. 198 pp.

14. Purcell, J.E., D. Grosse, and J.J. Glover. 1990. Mass abundances of abnormal Pacific herring larvae at a spawning ground in British Columbia. Transactions of the American Fisheries Society 119: 463-469.

15. Hose, J. E., M. D. McGurk, G. D. Marty, D. E. Hinton, E. D. Brown, and T. T. Baker. 1996. Sublethal effects of the *Exxon Valdez* oil spill on herring embryos and larvae: morphologic, cytogenetic, and histopathological assessments, 1989-1991. Can. J. Fish. Aquat. Sci. 53: 2355-2365.

16. McGurk, M.D. 1990. Early Life History of Pacific Herring: Prince William Sound Herring Larvae Survey. Final Report to NOAA-NOS, Contract 50ABNC-7-00141, Anchorage, Alaska.

17. McGurk, M.D. 1989. Advection, diffusion and mortality of Pacific herring larvae Clupea *harengus pallasi* in Bamfield Inlet, British Columbia. Mar. Ecol. Prog. Ser. 51: 1-18.

18. McGurk, M.D. 1984. Effects of delayed feeding and temperature on the age of irreversible starvation and on the rates of growth and mortality of Pacific herring larvae. Mar. Biol. 84: 13-26.

19. Norcross, B.L., M. Frandsen, J.E. Hose and E.D. Brown. 1996. Distribution, abundance, morphological condition, and cytogenetic abnormalities of larval herring in Prince William Sound, Alaska, following the *Exxon Valdez* oil spill. Can.J.Fish.Aquat.Sci. 53: 2376-2393.

20. Taylor, F.H.C. 1964. Life history and present status of British Columbia herring stocks. Bull. Fish. Res. Board Can. 143: 81 p.

21. Haegele, C.W. 1994. Juvenile herring surveys (1990-1993) in the Strait of Georgia. Proceedings of the Seventh Pacific Coast Herring Workshop, January 27-28, 1994; Canadian Tech. Rpt. Fish. Aquat. Sci. 2060: 23-37

22. Stokesbury, K.D.E., E.D. Brown, R.J. Foy, and B.L. Norcross. 1997. Juvenile herring growth and habitats. Annual Report for *Exxon Valdez* Oil Spill Trustee Council, Project 96320T, University of Alaska, Fairbanks. 69 pp.

23. Meyers, T.R., Short, S., Lipson, K., Batts, W.N., Winton, J.R., Wilcock, J., and Brown, E. 1994. Association of viral hemorrhagic septicemia virus with epizootic hemorrhages of the skin in Pacific herring *Clupea harengus pallasi* from Prince William Sound and Kodiak Island, Alaska, USA. Dis. Aquat. Org. 19: 27-37.

24. Brown, E.D., B.L Norcross, and J.W. Short. 1996a. An introduction to studies on the effects of the *Exxon Valdez* oil spill on early life history stages of Pacific herring, *Clupea pallasi*, in Prince William Sound, Alaska. Can J. Fish. Aq. Sci. 53: 2337-2342

25. Funk, F. 1995. Age-structured assessment of Pacific herring in Prince William Sound, Alaska and forecast of abundance for 1994. Alaska Department of Fish and Game, Regional Information Report No. 5J95-00, Juneau, AK. 40 pp.

References

26. Funk, F., and H. Savikko. 1989. Preliminary forecasts and projections for 1989 Alaska herring fisheries. Alaska Department of Fish and Game, Regional Information Report No. 5J89-02, Juneau, AK. 98 pp.

27. Short, J.W. and Harris, P.M. 1996. Petroleum hydrocarbons in caged mussels deployed in Prince William Sound, Alaska, after the *Exxon Valdez* oil spill. Am. Fish. Soc. Symp. No. 18: 29-39.

28. Moles, A. D., S. D. Rice and M. S. Okihiro. 1993. Herring parasite and tissue alterations following the *Exxon Valdez* oil spill. In Proceedings of the 1993 Oil Spill Conference, American Petroleum Institute Publication No. 4580. API, Washington, D.C. 20005. pp. 325-328

29. Carls, M. G., G. D. Marty, T. R. Meyers, R. E. Thomas, and S. D. Rice. In press. [a] Immunosuppression, expression of viral hemorrhagic septicemia virus, and mortality in pre-spawn Pacific herring (*Clupea pallasi*) exposed to weathered crude oil in the laboratory. Canadian Journal of Fisheries and Aquatic Sciences.

30. Marty, G. D., C. R. Davis, D. E. Hinton, T. R. Meyers, E. F. Freiberg, T. B. Farver, and J. Wilcock. 1995. *Ichthyophonus hoferi*, viral hemorrhagic septicemia virus, and other causes of morbidity in Pacific herring spawning in Prince William Sound in 1994. *Exxon Valdez* Oil spill Restoration Project 94320S Annual Report. 70 p.

31. Linden, O. 1976. The influence of crude oil and mixtures of crude oil/dispersants on the ontogenic development of the Baltic herring, *Clupea harengus* membras L. AMBIO 5(3): 136-140.

32. Rosenthal, H. and D. F. Alderdice. 1976. Sublethal effects of environmental stressors, natural and pollutional, on marine fish eggs and larvae. J. Fish. Res. Bd. Can. 33:2047-2065.

33. Pearson, W.H., E. Moksness, and J. R. Skalski. 1993. A field and laboratory assessment of oil spill effects on survival and reproduction of Pacific herring following the *Exxon Valdez* spill. Proceedings of the Third Symposium on Environmental Toxicology and Risk Assessment, ASTM, Atlanta, Georgia.

34. Kocan, R. M., J. E. Hose, E. D. Brown, and T. T. Baker. 1996a. Pacific herring (*Clupea pallasi*) embryo sensitivity to Prudhoe Bay petroleum hydrocarbons: laboratory evaluation and in situ exposure of embryos at oiled and unoiled sites in Prince William Sound. Can. J. Fish. Aquat. Sci. 53: 2366-2375.

35. Longwell, A. C. 1977. A genetic look at fish eggs and oil. Oceanus 20(4):46-58.

36. Longwell, A. C. and J. B. Hughes. 1980. Cytologic, cytogenetic and developmental state of Atlantic mackerel eggs from sea surface waters of the New York Bight, and prospects for biological effects monitoring with ichthyoplankton. Rapp. P.-v. Reun. Cons. int. Explor Mer 179: 275-291.

37. Long, E. R., M. F. Buchman, S. M. Bay, R. J. Breteler, R. S. Carr, P. M. Chapman, J. E. Hose, A. L. Lissner, J. Scott, and D. A. Wolfe. 1990. Comparative evaulation of five toxicity tests with sediments from San Francisco Bay and Tomales Bay, California. Environ. Toxicol. Chem. 9: 1193-1214.

38. Carls, M. G., S. W. Johnson, R. E. Thomas, and S. D. Rice. 1997. [b] Health and reproductive implications of exposure of Pacific herring (*Clupea pallasi*) adults and eggs to weathered crude oil, and reproductive condition of herring stock in Prince William Sound six years after the *Exxon Valdez* oil spill. Exxon Valdez Oil Spill Restoration Project 95074 Final Report.

39. Brown, E.D., T.T. Baker, J.E. Hose, R.M. Kocan, G.D. Marty, M.D. McGurk, B.L. Norcross, and J. Short. 1996b. Injury to the early life history stages of Pacific herring in Prince William Sound after the *Exxon Valdez* Oil Spill. Am. Fish. Soc. Symp. No. 18: 448-462.

40. McGurk, M.D. and E.D. Brown. 1996. Egg-larval mortality of Pacific herring in Prince William Sound, Alaska, after the *Exxon Valdez* oil spill. Can. J. Fish. Aquat. Sci. 53(10): 2343-2354.

41. Conover, R.J. 1971. Some relations between zooplankton and bunker C oil in Chedabucto Bay following the wreck of the tanker Arrow. Journal of the Fisheries Research Board of Canada 28:1327-1330.

42. Capuzzo, J.M. 1987. Biological effects of petroleum hydrocarbons: Assessments from experimental results.Pages 343-410 in D.F. Boesch and N.N. Rabalais (Eds.). Long-term environmental effects of offshore oil and gas development. Elsevier Applied Science Publishers, London.

43. Sturdevant, M.V., A.C. Wertheimer, and J.L. Lum. 1996. Diets of juvenile pink and chum salmon by hydrocarbons in Prince William Sound after the Exxon Valdez oil spill. Am. Fish. Soc. Symp. No. 18: 578-592.

44. Willette, M. 1996. Impacts of the *Exxon Valdez* oil spill on the migration, growth, and survival of juvenile pink salmon in Prince William Sound. Am. Fish. Soc. Symp. No. 18: 533-550.

45. Wertheimer, A.C., and A.G. Celewycz. 1996. Abundance and growth of juvenile pink salmon in oiled and non-oiled locations of western Prince William Sound after the *Exxon Valdez* oil spill. Am. Fish. Soc. Symp. 18:518-532.

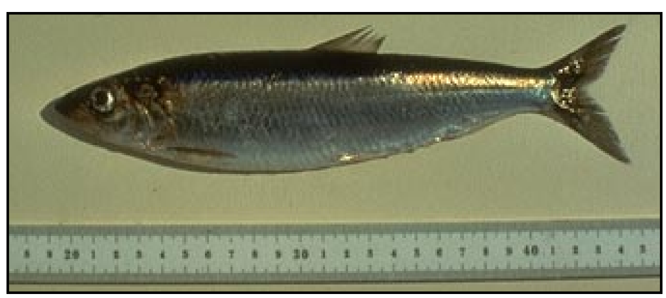
46. Carls, M.G., A.C. Wetheimer, J. W. Short, R.M. Smolowitz, and J.J. Stegeman. 1996. Contamination of juvenile pink and chum salmon by hydrocarbons in Prince William Sound after the *Exxon Valdez* oil spill. Am. Fish. Soc. Symp. 18:593-607.

47. Kocan, R. M., G. D. Marty, M. S. Okihiro, E. D. Brown, and T. T. Baker. 1996b. Reproductive success and histopathology of individual Prince William Sound Pacific herring 3 years after the *Exxon Valdez* oil spill. Can. J. Fish. Aquat. Sci. 53: 2388-2393.

48. Johnson, S.W., M.G. Carls, R.P. Stone, C.C. Broderson, and S.D. Rice. 1997. Reproductive success of Pacific herring (*Clupea pallasi*) in Prince William Sound, Alaska, six years after the *Exxon Valdez* oil spill. Fishery Bulletin 95:748-761.

49. Carls, M.G., L. Holland, M. Larsen, J.L. Lum, D.G. Mortensen, S.Y. Wang, and A.C. Wertheimer. 1996. Growth, feeding and survival of pink salmon fry exposed to food contaminated with crude oil. Am. Fish. Soc. Symp. 18:608-618.

50. Paul, A.J. and J.M. Paul, 1998, Fall and spring somatic energy content for Alaskan Pacific herring (*Clupea pallasi* Valenciennes 1847) J. of Experimental Marine Biology and Ecology, 226:75-86.



Adult Pacific herring greater than 170 mm in length and 80 grams in weight can spawn, usually beginning at the age of 3. Herring in the Prince William Sound population live up to 12 years.