87-e14

Segment No. 11-24-01

ANDREA BEATTY RINIKER
Director

STATE OF WASHINGTON
DEPARTMENT OF ECOLOGY
7272 Cleanwater Lane, LU-11 • Olympia, Washington 98504-6811 • (206) 753-2353

TO: Jon Neel and Gary Bailey

THROUGH: Bill Yake BY

FROM: Art Johnson AJ

SUBJECT: Review of Data on Sevin

DATE: July 1, 1987

In response to your request of March 6, 1987, I have completed a review of data relevant to the environmental effects of applying the pesticide Sevin (carbaryl) to control burrowing shrimp in Willapa Bay and Grays Harbor oyster beds. The objective of the review was to determine if sufficient, quality data exist to answer the following questions:

- How long do carbaryl and its primary hydrolysis product 1-naphthol persist in the water column?
- What concentrations of carbaryl and 1-naphthol in water are toxic to marine organisms?
- How long do carbaryl and 1-naphthol persist in the sediments?
- What concentrations of carbaryl and 1-naphthol in sediment are toxic to marine organisms?
- What are the effects on abundance and diversity of infauna?
- What are the effects on abundance and diversity of epifauna?
- What mortality is experienced by Dungeness crab and how does this affect the fishery?
- What mortality is experienced by fish?
- Are birds adversely affected?
- What are the potential ecological impacts of Sevin applications?

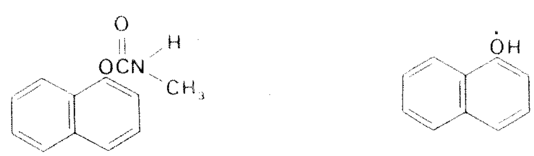
These questions basically represent a refinement of information needs outlined in the conclusion of the EIS. The biology of burrowing shrimp and mitigation measures were cited in the EIS as additional information gaps but were not addressed in this review. The issues of the need to spray, economic impacts, and policy implications involved in granting water quality modifications were also not addressed.

The information reviewed included reports and unpublished data from the Washington State Department of Fisheries (Fisheries) and University of Washington, College of Fisheries (UW), and a review of the EIS and other literature. All available Fisheries and UW reports and data were reviewed. The literature review was not exhaustive, but did include the major body of work on the subject of marine impacts of Sevin.

For each of the questions listed above, the available data are summarized, shortcomings in individual studies noted (sample handling, analytical methods, study design, etc.), remaining data gaps identified, and relevant information from the literature discussed. Based on results of this review, the questions that require additional research and can be answered with some confidence in a reasonable time frame are outlined.

While this review is critical of some Fisheries studies, it should be recognized that Fisheries has not had adequate resources to conduct a comprehensive study of this complex problem, but has made every reasonable effort compatible with burrowing shrimp control to reduce adverse environmental impacts. Eric Hurlburt, Dennis Tufts, and Marvin Tarr generously provided reports, unpublished data, pertinent literature, and information from field experience.

BACKGROUND



Carbaryl and its primary hydrolysis product 1-naphthol

The carbamate pesticide Sevin (carbaryl; 1-naphthyl-N-methylcarbamate; CAS reg. no. 63-25-2) has been used on an annual basis to kill ghost shrimp (Callianassa californiensis) and mud shrimp (Upogebia pugettensis) on oyster beds in Willapa Bay and Grays Harbor since about 1963. The burrowing and feeding habits of these shrimp soften the substrate. Significant infestations can cause oysters, particularly seed oysters, to sink into the substrate or be smothered by silt. It is the contention of the oyster growers that shrimp control is necessary to maintain oyster production at its current level using present culture methods.

The first experiments with marine application of Sevin were on the east coast in the late 1950s and early 1960s to control oyster drills. Since that time the marine use of Sevin has been limited to Washington State and Tillamook Bay, Oregon. A 1984 Court of Appeals ruling that spray permits did not comply with state land use goals protecting estuaries has stopped its use in Tillamook Bay. The court ruled the Oregon Fish and Wildlife Commission could not protect the estuary without determining what organisms live there and if Sevin would adversely affect them.

Fisheries authorizes and regulates Sevin application under WAC 220-20-10(16). Use must comply with provisions of Washington State Special Local Needs Pesticide Registration No. WA760021 issued by EPA through the Washington State Department of Agriculture under authority of section 24(c) of the Ammended Federal Insecticide, Fungicide, and Rodenticide Act. Fisheries began issuing declarations of nonsignificance in 1976 when criteria for the use and application of Sevin were first set (Appendix). Ecology has been granting water quality modifications for spray projects under WAC 173-201-035(8)(e), thereby certifying that there will be no interference with existing water uses or long-term and irreparable harm to the environment.

Annual treatment has been generally limited to 300 acres in Willapa Bay and 100 acres in Grays Harbor. (Fisheries has also allowed one Sevin treatment in Puget Sound--14 acres in Liberty Bay were treated in 1982.) In 1984 poor oyster growth and increased populations of burrowing shrimp--attributed to an El Nino in 1982 and 1983--prompted the oyster growers to request treatment of 768.5 acres. Fisheries and Ecology authorized expanded spraying after receiving permission from EPA and FDA; 488 acres were subsequently treated (396 acres in Willapa Bay). Through 1984, Sevin has been applied as a wettable powder at a rate of 10 lbs. active ingredient (a.i.) per acre; in 1985 and 1986 the rate was 7.5 lbs. per acre. Beginning in 1984, EPA allowed treatment over seed oysters. Prior to that time, only bare ground could be treated. The treatment period is limited to July and August.

As a result of public and agency concern, Fisheries and Ecology completed an EIS in 1985. As already mentioned, the EIS concluded that there were insufficient data to answer a number of environmental questions. Fisheries and the UW have been engaged in research to answer some of these questions. Reservations about continuing to grant water quality modifications and the absence of plans to conduct all research needed to complete a supplemental EIS for continued and expanded treatment prompted Ecology to take the following course of action (Riniker, 1986):

1. "During 1986, (Ecology) will continue to process water quality modifications to allow the use of Sevin as in the past."

2. "In 1987, only those projects which are involved in research to answer the questions raised in our joint EIS and useful toward finalizing a SEIS will receive water quality modification approval for the use of Sevin."

3. "After 1987, no water quality modification will be authorized for Sevin unless an SEIS is finalized."

DATA REVIEW

o <u>How long do carbaryl and its primary hydrolysis product 1-naphthol persist in the water column?</u>

Fisheries Studies:

Fisheries has reported data on carbaryl and 1-naphthol concentrations in water samples collected from Quilcene Bay in August 1963 (Chambers, 1970) and Willapa Bay in July of 1984, 1985, and 1986 (Hurlburt, 1985; Creekman and Hurlburt, 1987; Anonymous, 1986 draft).

In the 1963 Quilcene Bay study, two plots (20'x40') were sprayed with Sevin (wettable powder) at 5 or 10 lbs. a.i. per acre. The analyses were done by Union Carbide using an unspecified method. Results are reported as Sevin; no mention is made of the hydrolysis product 1-naphthol. Samples were of the first 1/2 inch of flood waters covering the plots.

Sevin concentrations[1] of 0.05 to 0.10 parts per million (ppm) were measured in samples collected prior to application; this was attributed to "interferences by sample substances." The "sensitivity" of the analytical method was reported to be 0.05 to 0.12 ppm. On the day of application, Sevin concentrations were 0.42 to 0.65 ppm. Fourteen days later, replicate samples from the plot treated at a rate of 10 lbs. per acre both had 0.52 ppm (Fisheries considers this data point to be an "anomaly" [Hurlburt, personal communication].) The plot treated at 5 lbs. per acre had no Sevin detected (i.e., <0.12 ppm).

Data are also reported on water samples collected from a separate plot on the first flood tide after application of wettable powder at 10 lbs. per acre. Surface samples taken when the water depth was 1/2 inch had 0.04 to 3.22 ppm. When the water depth had risen to 6 inches, surface water samples had none detected (detection limits 0.05-0.07 ppm); bottom water samples had 0.10 to 0.11 ppm.

The 1984 Willapa Bay study involved analysis of bottom water samples collected over a four-hour period following application of 10 lbs. per acre to two tracts of 17 and 20 acres. Data are reported for carbaryl (analyzed by gas chromatography [GC] at the DSHS Wenatchee laboratory) and for carbaryl+1-naphthol (analyzed by a colorimetric method [Linaraja and Venugopalan, 1979] at Fisheries Point Whitney Shellfish Laboratory). Detection limits were 0.0001 ppm for carbaryl and 0.1 ppm for carbaryl+1-naphthol.

[1] Refer to Table 1 to put the potential significance of the concentrations discussed here in perspective.

The Point Whitney laboratory has provided information on sample handling and analysis for the 1984 samples (Tarr, 1987, personal communication). Because carbaryl is not stable at the pH of seawater, samples for colorimetric analysis were acidified in the field to pH 4.5 to 5.0 and iced. The samples sent to the Wenatchee laboratory were placed on ice only, acidification not being appropriate for GC analysis. Holding time before extraction for GC analysis was four days (collected 13 July, extracted 17 July). Samples for carbaryl analysis should be extracted within 24 hours of collection (Rieck, 1987, personal communication). This compromises the quality of the carbaryl data and may explain, in part, the wide variation in concentrations measured by the two methods during the first 15 minutes of sampling (see below) as well as the apparent rapid disappearance of carbaryl.

A single, combined mean concentration is reported for both tracts for each sampling period. Initial concentrations averaged 10.6 ppm carbaryl+1-naphthol and 3.07 ppm carbaryl. At 15 minutes, concentrations were 0.1 ppm carbaryl+1-naphthol and 0.002 ppm carbaryl. For the remainder of the four-hour monitoring period, carbaryl+1-naphthol was reported at 0.0 (i.e., <0.1 ppm); carbaryl concentrations reportedly varied between 0.0 (i.e., <0.0001) and 0.002 ppm. The text refers to a carbaryl+1-naphthol concentration of 0.037 ppm at four hours but suggests it "may be due to a sampling or analysis artifact." These data could be better evaluated if data for individual samples were reported rather than simple means.

The above investigations did not consider transport of carbaryl and 1-naphthol away from the site of application. This was the object of the 1985 and 1986 studies.

In 1985 bottom water samples were collected from the leading edge (2-5 inches total water depth) of the first flood tide after application of 7.5 lbs. per acre to a 40-acre Willapa Bay tract. This is the first Fisheries report to specify sample collection, preservation, and analytical methods. Although the data are reported as Sevin, the analytical method (Karinen, et al., 1967) measures both carbaryl and 1-naphthol. Fisheries has not evaluated the comparability of the two colorimetric methods used for carbaryl analysis in 1984 and 1985 (Tarr, 1987, personal communication).

The path of the incoming water was followed for a period of 71 minutes from the center of the tract to 217 yards beyond the tract boundary. Mean carbaryl+1-naphthol concentrations ranged from 1.9 to 5.2 ppm on the tract to 0.7 to 7.9 ppm off the tract. The mean concentration 217 yards from the tract boundary was 2.5 ppm.

A similar study was done in 1986. Bottom water samples were collected on the incoming tide at three tracts; the application rate was 7.5 lbs. per acre. One 22-acre tract had 7.5 to 26.2 ppm carbaryl and 0.3 to 1.3 ppm 1-naphthol on-site. Both carbaryl and 1-naphthol were detectable (0.1 ppm) up to 250 yards beyond the tract boundary. One sample at 500 yards had 0.1 ppm 1-naphthol. The other two tracts monitored (4 and 33 acres) had much lower concentrations, both on- and off-site. However, in both instances, carbaryl and 1-naphthol were detectable (0.1 ppm) up to approximately 500 yards and 700 yards, respectively, from the tracts' boundaries.

Shortcomings in the above studies can be summarized as follows:

1. Sample handling and analytical methods for the 1984 studies were not adequately documented; the GC data probably underestimate actual concentrations.

2. None of the studies provide quality assurance data to assess the accuracy of the concentrations reported.

3. Carbaryl and 1-naphthol are toxic to a number of marine organisms, especially crustaceans, at concentrations well below the detection limit of 0.1 ppm employed in most of these analyses. The "zero" concentrations reported among these data may in fact represent toxic concentrations, depending on the period of exposure (see Table 1).

4. The maximum post-application monitoring period in the 1984-1986 studies was four hours. A longer monitoring period is needed, given the difficulty in assessing the accuracy of the 1963 Quilcene Bay data. There is a potential for resuspension of contaminated sediments into the water column for a period that may exceed one month (see discussion of persistence in sediment).

5. The largest Sevin applications have not been monitored. For example, in 1984, 10 tracts constituting 80 acres in Stackpole Harbor, Willapa Bay, were treated the same day; a 92-acre tract in Southbay, Grays Harbor, was treated over four days (Hurlburt, 1986).

Other Data:

The EIS cites Karinen, et al. (1967) in assessing the persistence of carbaryl in seawater. Karinen found carbaryl and 1-naphthol concentrations in water declined to less than 10 percent in 10 days in aquaria containing seawater and mud. Both compounds were absorbed by mud where decomposition continued at a slower rate. Without mud the rate of decline in water concentrations was slowed. Degradation products were carbon dioxide and, possibly, methane.

The persistence of carbaryl and 1-naphthol in water varies with pH, light, dissolved oxygen, temperature, salinity, and biological activity. Carbaryl and 1-naphthol degrade more rapidly in alkaline than acidic waters (Lamberton and Claeys, 1970; Aly and El-Dib, 1971; Sikka et al., 1975). Lamberton and Claeys (1970) found 1-naphthol was unstable at the pH of normal seawater, 8.2. The degradation of 1-naphthol is enhanced by light, and it is relatively stable under anaerobic conditions (Lamberton and Claeys, 1970; Liu, et al., 1981). Carbaryl and 1-naphthol degradation rates vary directly with temperature (Aly and El-Dib, 1971; Karinen, et al., 1967). The half-life of carbaryl in freshwater has been reported to vary from 1.3 to 10.5 days in laboratory experiments (Kanazawa, 1975; Eichelberger and Lichtenberg, 1971; Stanley and Trial, 1980; Aly and El-Dib, 1971). Lamberton's and Claeys' (1970) experiments suggest a half-life on the order of five days for 1-naphthol in seawater.

o *What concentrations of carbaryl and 1-naphthol in water are toxic to marine organisms?*

There have been no site-specific studies in Willapa Bay or Grays Harbor relating carbaryl or 1-naphthol concentrations in water to toxic effects on marine organisms.

Butler (1962) reported that five species of phytoplankton used by mollusc larvae as food could not tolerate continuous exposure to carbaryl at concentrations higher than 0.1 ppm. Ukeles (1962) found that after an incubation period of 10 days, 1 ppm completely suppressed growth of two species of marine algae; 10 ppm was lethal to three species. No information is available on toxicity to eelgrass (*Zostera* spp.).

Table 1 summarizes acute toxicity data for local marine invertebrates and fishes. In applying this data to Willapa Bay and Grays Harbor, it is important to consider the potential duration of exposure as well as concentration.

Carbaryl is much more toxic to crustaceans than to molluscs or fishes. The available data also indicate 1-naphthol is less toxic to crustaceans than carbaryl but somewhat more toxic than carbaryl to molluscs and fishes.

In 10-week aquarium experiments employing 0.001, 0.01, and 0.1 ppm of carbaryl, the average number of species (molluscs, arthropods, annelids, and nemerteans) was significantly less in aquaria with 0.01 and 0.1 ppm. There were significantly fewer numbers of the amphipod *Corophium acherusicum* at all concentrations relative to controls (Tagatz, *et al.*, 1979).

Tagatz's experiments furnish the only chronic toxicity data for marine invertebrates; no toxicity data are available for chronic exposure of fish to carbaryl or 1-naphthol. Carbaryl is not known to be carcinogenic or teratogenic; it is classed as a weak mutagen (EPA, 1984a, b).

EPA has not established water quality criteria for carbaryl or 1-naphthol. The National Academy of Sciences (1973) recommends that the maximum concentration of carbaryl in freshwaters should not exceed 0.00002 ppm (20 pptrillion) to protect aquatic life. This recommendation was derived by multiplying concentrations acutely toxic to sensitive species by a safety factor of 0.01.

Subacute effects of carbaryl have been observed at concentrations of 1 ppm and lower. Continuous exposure to 1 ppm caused 40 percent reduction in normal oyster development (Davis, 1961). Feeding activity of the lugworm (*Arenicola cristata*) was significantly reduced at 1 ppm (Tagatz, *et al.*, 1979). Buchanan, *et al.* (1970) observed delayed molting of Dungeness crab larvae when exposed to carbaryl concentrations as low as 0.0001 ppm over a 25-day period. Weis and Weis (1974, 1976) found 0.01 ppm caused optic and skeletal malformation in silversides (*Menidia menidia*) eggs and retarded regeneration of caudal fins in killifish (*Fundulus heteroclitus*).

Table 1. Acute toxicity of carbaryl and 1-naphthol in seawater bioassays with various life stages of estuarine organisms (EC-50[1] in ppm).

Species	Carbaryl			1-Naphthol	
	24h	48h	96h	24h	48h
Crustaceans					
Mud shrimp-Larvae (*Upobegia pugettensis*)	0.03-0.16	0.03-0.14	--	6.2-13.7	2.8-5.6
Ghost shrimp-Adult (*Callianassa californiensis*)	0.13	--	--	6.6	--
Ghost shrimp-Larvae	0.17-0.47	0.03-0.08	--	16.6-22.1	2.1-4.5
Dungeness crab-Adult (*Cancer magister*)	0.49	--	0.26	37.0-60.0	--
Dungeness crab-Juvenile 9th stage	0.35-0.70	--	--	--	--
Dungeness crab-Juvenile 2nd stage	0.076	0.057	--	--	--
Dungeness crab-Larvae	0.08	0.005	0.01	--	--
Molluscs					
Bay mussel-Larvae (*Mytilus edulis*)	--	1.4-2.9	--	--	0.8-2.2
Pacific oyster-Larvae (*Crassostrea gigas*)	--	1.5-2.7	--	--	0.6-1.1
Cockle clam-Juvenile (*Clinocardium nuttali*)	7.3	--	3.75	5.1-7.8	--
Fishes					
English sole-Juvenile (*Parophrys vetulus*)	3.2-5.2	--	--	2.4-2.7	--
Shiner perch-Juvenile (*Cymatogaster aggregata*)	3.8-4.0	--	--	1.3-1.8	--
Threespine stickleback-Juv. (*Gasterosteus aculeatus*)	5.5-7.7	--	--	2.8-3.5	--
Coho salmon-Juvenile (*Oncorhynchus kisutch*)	2.95	2.7	1.3	--	--

Data sources: cabaryl data are from Stewart, *et al.* (1967); Butler, *et al.* (1968); and Buchanan, *et al.* (1970), as summarized in Bunchanan, *et al.* (1985) except coho data which are from Post and Schroeder (1971). 1-Naphthol data are from Stewart, *et al.* (1967).

[1]EC-50 is the concentration producing death or irreversible paralysis in 50 percent of the test animals.

Buchanan, et al. (1985) point out that carbaryl toxicity increases with temperature. The 24-hour EC-50 (death or paralysis) for adult Dungeness crabs was 0.49 ppm at 11^{o}C and 0.32 ppm at 18^{o}C (Buchanan, et al., 1970). Forty-eight-hour EC-50s for death of mud shrimp larvae at 16 and 20^{o}C were 0.09 and 0.04 ppm, respectively (Stewart, et al., 1967).

o How long do carbaryl and 1-naphthol persist in the sediments?

Fisheries Studies:

Fisheries has reported data on carbaryl and 1-naphthol concentrations in sediment samples collected from Quilcene Bay in August, 1963 (Chambers, 1970) and from Willapa Bay in August of 1968 (Sayce, 1970) and 1983 (Hurlburt, 1986).

The data for Quilcene Bay come from the two-plot study previously described. The day prior to application Sevin concentrations in the top 1/2 inch of sediment were "none" to 0.06 ppm. Detection limits were reported to be 0.04 to 0.10 ppm. The day of treatment, the plot that received 10 lbs. per acre had 2.24 and 2.30 ppm in replicate sediment samples. The 5 lbs. per acre plot had 0.90 and 1.18 ppm. Fourteen days after application concentrations ranged from 0.05 to 0.26 ppm. The highest concentrations were in the 5 lbs. per acre plot. The elevated concentrations at 14 days were described as being "in the range covered by interfering substances." The basis for this conclusion relative to the highest concentration measured (0.26 ppm) is not apparent, given the detection limits reported.

The 1968 Willapa Bay study followed sediment concentrations after treatment of 10 acres at 10 lbs. per acre. The thickness of the sediment layer sampled is not indicated. Analysis was done at the UW by an unspecified method. The results are for carbaryl+1-naphthol. No detection limits are given. The following data are reported (ppm): day 0 - 0.00; day 1 - 1.10; day 2 - 0.35; day 4 - 0.06; day 8 - 0.01; day 16 - 0.00 (i.e., below detection limits). (The EIS cites this study as showing that sediments remove carbaryl from the water column "without subsequent release." Since no water analyses were done in the study the basis for this statement is unfounded.)

A second sediment study was done in Willapa Bay in 1983 on a five-acre tract treated at 10 lbs. per acre. Samples were of the top 1-inch surface layer. No information is given on sample collection or preservation. Analysis was done by high pressure liquid chromatography at Lauck's Laboratory, Seattle (Owens, 1987, personal communication). Results are reported as Sevin (dry weight basis) with a lower detection limit of 0.05 ppm; 1-naphthol was not analyzed. Laucks reported a 94 percent recovery of a carbaryl spike. Table 2 shows the results obtained.

Table 2. Fisheries data on Sevin concentrations in sediment samples from a five-acre Willapa Bay tract treated in 1983.

Sample Number	Relation to Spraying	Sevin (ppm)
1	Before	none detected (i.e., <0.05 ppm)
2	"	" " " "
3	Immediately after	0.3
4	" "	11.0
5	" "	0.6
6	" "	1.4
		3.3 average
7	2 hours after	2.6
8	" " "	0.2
		1.4 average
9	3 hours after	4.2
10	" " "	0.9
		2.6 average
11	24 hours after	1.1
12	" " "	0.3
		0.7 average

In summarizing these data the report states "Sevin concentrations in sediment dropped quickly after spraying. After 24 hours Sevin was present in concentrations 3 to 9 percent of the initial level." Neither statement is substantiated by the data.

Shortcomings in the above studies can be summarized as follows:

1. Insufficient quality assurance data are reported to assess the accuracy of the data.

2. Sampling and analytical methods are not adequately described.

3. The comparability of analytical methods used has not been established.

4. Based on the results of Chambers and Karinen _et al_. (see below) the monitoring period in 1983 was not long enough.

5. 1-Naphthol was not measured in the 1983 study.

6. No off-site sediment sampling has been done.

7. No subsurface sampling has been done. Carbaryl may penetrate to a depth of more than three inches (see Karinen below).

Other Data:

Karinen, et al. (1967) treated a 25' x 25' plot in Yaquina Bay, Oregon, at 10 lbs. per acre. Initial concentrations were 5.4 ppm carbaryl and 10.7 ppm carbaryl+1-naphthol. At the end of the 42-day experiment, carbaryl concentrations were 0.1 ppm (top 1 inch), 0.2 ppm (2 to 3 inches), and 0.08 ppm (4 to 6 inches). 1-Naphthol levels were low after the first day, suggesting carbaryl hydrolysis is slow in mud. Temperatures during this study were 7.5 to 14.0°C which is colder than those during Fisheries studies and likely to have retarded degradation.

Freshwater sediments remained toxic to insect larvae three months after Sevin application (Mulla, 1960).

Buchanan, et al. (1985) discuss circumstantial evidence for the persistence of carbaryl (or 1-naphthol) in estuarine sediments:

> "Sevin concentrations found in treated mud flats after 42 days (0.1 to 0.2 ppm) are certainly above the concentration (0.076 ppm) that will kill second-stage juvenile Dungeness crab when exposed to Sevin in seawater bioassays for 24 hours. Armstrong and Milleman (1974) found that Sevin continued to reduce ghost shrimp populations 11 months after application. The mean number of shrimp holes/m2 were 161 in the control plot, and 32 and 25 in the treatment plots of 2.3 and 4.6 kg/acre of active Sevin, respectively. These reduced populations could stem from long-term toxicity of Sevin or failure of the ghost shrimp populations to re-colonize. Also, estuarine flats treated with Sevin to control burrowing shrimp only required retreatment every three or four years (Oregon Department Fish and Wildlife, 1982). It is reasonable to assume that Sevin may also have a long-term effect on recruitment of non-target invertebrates in treated tideflats."

Fisheries records for Willapa Bay substantiate that it may take a number of years for burrowing shrimp populations to return to pretreatment levels. Tufts (1983) states "Many tracts have been treated only once in 18 years, others two or three times, less than one-third have been treated more than four times. On the average, a tract is treated once in six years or 2.9 times in 18 years." The basis for this statement is the data in Table 3. It should be recognized that failure to recolonize may be due to factors other than toxicity. Fisheries considers this to be normal for a species reproducing once a year, and consistent with recovery rates of other benthic invertebrate populations (Hurlburt, 1987, personal communication).

Table 3. Fisheries data on frequency of Sevin treatments to Willapa Bay oyster beds, 1963-1980.

Total tracts treated 1963-80			171	
Times treated	1	2	3	4 or more
Number of tracts treated	70	20	33	48
Percentage of total number of tracts treated	41%	12%	19%	28%

Lamberton and Claeys (1970) found 1-naphthol formed a precipitate in seawater that was two-thirds as toxic as 1-naphthol. The precipitate contained a stable free radical and appeared to be a cholinesterase inhibitor. The persistence of the precipitate was offered as a potential explanation for "observations of treated mud flats which failed to recolonize 18 months after treatment with carbaryl." The authors did not indicate the source of the observations to which they referred.

- <u>What concentrations of carbaryl and 1-naphthol in sediment are toxic to marine organisms?</u>

No data are available on this subject. Circumstantial evidence suggests the potential for toxic effects at or below 0.1 ppm in sediment (see above).

- <u>What are the effects on abundance and diversity of infauna?</u>

Fisheries Studies:

Fisheries has collected infauna samples from Willapa Bay in 1984 (Hurlburt, 1986), 1985 (Creekman and Hurlburt, 1987), and 1986 (Tufts, 1987, personal communication). Chambers (1970) reported mortality of clams and polychaetes following Sevin application in Grays Harbor in 1962, but did not count the numbers of dead animals.

In the 1984 Willapa Bay study, a five-acre tract, last treated in 1978, was sampled prior to treatment (10 lbs. per acre), and 24 hours and 60 days after treatment. Samples were 182 square cm x 17.5 cm cores sieved through a 1 mm screen. Data were obtained on species abundance and biomass. The species abundance data are summarized in Table 4.

Table 4. Summary of Fisheries data on infauna abundance before and after treatment of a five-acre tract in Willapa Bay in 1984 (number of individuals per core).

Species	Pre-treatment	24 hours	60 days
Crustaceans			
Amphithoe valida	0	0	0.11
Callianassa californiensis	0	0.44	0
Corophium aschericum	0.17	0.17	0
Leptochelia dubia	0	0.17	0
Upogebia pugettensis	0.17	0	0
Molluscs			
Cryptomya californica	0.33	0.44	0.22
Macoma balthica	1.83	1.33	0.33
Macoma nasuta	0.17	0.17	0.44
Polychaetes			
Nephtys caecoides	0.67	0.17	0.89
Nereis vexillosa	2.00	3.00	0.11
Pectinaria granulata	7.83	0.33	0.11
Pherusa sp.	1.50	2.11	1.89
Other			
Diptera larva	0	0.17	0
Mean number per core	14.50	7.67	4.11
Total number of species	9	11	7
Number of samples	6	9	9

The report characterizes the results as "inconclusive" but also states that the results "suggest that recolonization can occur rapidly." Rapid recolonization is not demonstrated by these data.

The primary shortcomings in this study are:

1. No samples were analyzed from control sites.

2. The number of animals enumerated, especially crustaceans, was too small to detect an impact. Without control data it cannot be determined whether the study area was representative of a normal tideflat community or had not recovered from past treatments or drift from adjacent applications.

3. A 60-day study is not long enough to document recovery of infauna.

Fisheries collected approximately 200 infauna samples from treated and control areas in Willapa Bay in 1985. Sieve size was 0.5 mm. These samples have not been analyzed.

Fisheries has also made shrimp burrow counts in connection with the previously described 1986 study of off-site transport of carbaryl and 1-naphthol in Willapa Bay. These data (Tufts, 1987, unpublished) suggest Sevin application killed burrowing shrimp up to approximately 100 feet beyond tract boundaries.

Overall, there are insufficient data on the question of Sevin's impact on benthic infauna in Willapa Bay and Grays Harbor.

Other Data:

Snow and Stewart (1963) observed dead polychaetes after a field treatment in Tillamook Bay.

Armstrong and Millemann (1974) found that application of Sevin to experimental plots in Yaquina Bay significantly reduced the numbers of juvenile clams over the course of the 30-day study. Polychaetes were not significantly affected which contrasts with the results of Chambers (1970) and Snow and Stewart (1963). The authors suggest this was due to the fine particle size of the sediment which impeded downward movement of the pesticide.

o <u>What are the effects on the abundance and diversity of epifauna?</u>

Fisheries Studies:

Data on epifauna (other than Dungeness crab which are reviewed later) are limited to 1/4 square meter quadrat samples taken in conjunction with the previously described infauna cores in Willapa Bay in 1984 (Hurlburt, 1986). The epifauna data, summarized in Table 5, suffer from the same shortcomings noted for infauna.

Table 5. Summary of Fisheries data on epifauna abundance before and after treatment of a five-acre tract in Willapa Bay in 1984 (number of individuals per quadrat).

Species	Pretreatment	24 hours	60 days
Crustacea			
Balanus sp.	61.7	39.2	76.3
Gnorimosphaeroma lutea	0.33	0	0
Cancer magister	0	0.17	0
Molluscs			
Crassostrea gigas	10.3	6.67	6.83
Mytilus edulis	5.33	4.67	5.83
Modiolus demissus	0.17	0	0
Pododesmus macroschisma	0	0.17	0
Coelenterate			
Anemone sp.	1.50	0.50	2.00
Mean number per quadrat	79.3	51.2	91.0
Total number of species	6	6	4
Number of samples	6	6	6

o <u>What mortality is experienced by Dungeness crab and how does this affect the fishery?</u>

Fisheries Studies:

Fisheries has made post-treatment estimates of Dungeness crab mortalities in Willapa Bay and Grays Harbor since 1976 (EIS; Hurlburt, 1986; Creekman and Hurlburt, 1987; Hurlburt, 1987, personal communication). In 1984 a pre-treatment estimate was obtained of young-of-the-year (YOY) crab populations on five tracts proposed for spraying (Hurlburt, 1986). Fisheries has also made a preliminary assessment of the impact on the fishery (Hurlburt, 1987).

Post-treatment inspections by Fisheries are done during low tide 24 hours after spraying. Dead crab are counted within 10-foot to 20-foot wide by 100-foot long plots; at least 5 percent of the area of each tract is walked. Subsamples of crabs are sexed and aged. Table 6 summarizes the data obtained through 1986.

Table 6. Fisheries estimates of crab mortality on oyster beds treated with Sevin in Willapa Bay and Grays Harbor, 1977-1986.

Year	Acres Treated	Estimated Total Number of Crab Killed
1977	162	4,180
1978	149	2,697
1979	314	5,181
1980	251	12,726
1981	120	5,730
1982	272	10,572
1983	244	14,608
1984	488	38,410
1985	392	59,933
1986	398	16,260

Beginning in 1984 Fisheries set crab kill quotas based on the historical average number of dead crabs counted per acre. A quota of 9000 crab (30 crab per acre x 300 acres) was set for Willapa Bay to control crab mortality during treatment of the additional acreage requested that year. Because of unexpected large numbers of YOY and in consideration of the natural high mortality of this age group, 10 YOY were counted as 1 sublegal adult equivalent (SLAe; i.e., 1+ crab and older). Prior to 1984 Fisheries had primarily seen older crab killed by Sevin treatments. Ultimately, 7979 SLAe, or 89 percent of the 9000 limit, were estimated to have been killed in Willapa Bay. The total kill estimate in Willapa Bay was 26,234--77 percent of which were YOY.

In 1985, individual quotas (30 SLAe per acre) were assigned to place responsibility for crab losses on individual growers. Three 1+ age crab were counted as 1 SLAe to allow for survivors of the large 1984 year class. Ten YOY continued to count as 1 SLAe. Owners were not penalized for quota violations by others. The average SLAe kill per acre was estimated at 50 in Willapa Bay and 49 in Grays Harbor. The total SLAe kill estimate was 19,725, of which 88 percent were 1+ crab.

Settlement of YOY was especially light in 1986. The total summer population of Dungeness crab in Willapa Bay was estimated to be half that in 1985 (Armstrong, 1987). Crab mortalities were estimated at 16,260. Most crabs were 1+ age. This was equivalent to 9132 SLAe and within Fisheries 30 SLAe/acre guideline (398 acres treated).

Concern for the large number of YOY crab in 1984 prompted Fisheries to make an assessment of crab abundance prior to several commercial applications that year. Test plots (typically 10' x 100') on four tracts in Willapa Bay and one tract in Grays Harbor were hand-treated with Sevin. Table 7 summarizes the population estimates based on test plot counts and compares them with mortality estimates from Fisheries routine post-treatment inspections.

Table 7. Fisheries assessment of Dungeness crab populations on tracts in Willapa Bay and Grays Harbor prior to treatment in 1984.

Permit Number	Tract Size (acre)	Date	Crab/ Plot	Crab/ Acre	Estimated Population	Post-Treatment Mortality Estimate
Willapa Bay						
8404	30	7/28	0	0	0	not treated
8419	20	7/26	3	131	2620	479
8426	48	7/24	8	1742	83616	
		7/25	3	261	12528	
		Average		1002	48072	4368
8437	15	7/27	1	44	660	784
Grays Harbor						
8433	46.8	7/30	1	44	4048	
		7/30	4	174	16008	
		7/30	2	87	8004	
		Average		102	9534	4456

Of the four tracts where before and after assessments were made, two showed reasonable agreement between estimated populations prior to treatment and estimated numbers of crabs killed. For the other two tracts, however, post-treatment assessment potentially underestimated actual crab mortality by an order of magnitude. The discrepancy on plot #8426 alone represents roughly half of the 9000 SLAe quota for Willapa Bay that year.

The small size of the plots poisoned for the pre-treatment assessments in 1984 and resulting low numbers of crab per plot reduce the confidence of these population estimates. Fisheries is of the opinion that it is not feasible to treat large enough areas for a reliable estimate of crab populations prior to commercial applications (Hurlburt, 1986).

Fisheries is aware that post-treatment inspections underestimate the number of YOY killed. YOY (<40 mm carapace width) are difficult to see on the tide flats and an unknown number are eaten or washed away in the 24 hours between treatment and inspection. Results from UW research on Sevin-related crab mortality also show the need of improved mortality assessment (see discussion of UW studies, below).

Fisheries has observed "high concentrations of dead SLA crab mortalities adjacent to river channels and major sloughs" and concluded that "it appears generally more SLA crabs are killed because they move into treated areas from adjacent subtidal habitats and feed on dead shrimp" (Hurlburt, 1986). Buchanan, et al. (1970) observed Dungeness crab were killed or paralyzed within six hours after feeding on clams that had been exposed to Sevin. Fisheries has obtained the following data (Table 8) on carbaryl and 1-naphthol concentrations in burrowing shrimp and other organisms collected during spray projects in Willapa Bay and Grays Harbor.

Table 8. Fisheries data on carbaryl and 1-naphthol in organisms exposed to Sevin in Willapa Bay and Grays Harbor.

Species	Exposure (lbs./ acre)	Relation to spray	Concentration (ppm, wet weight)	Reference
Mud and ghost shrimp	5-10	day 1	5-12 carbaryl	Tufts, 1987, personal communication
Polychaetes	5-10	"	approx. 25 "	"
Mud and	5	day 0	7.1 "	Creekman and Hurlburt,
ghost shrimp	7.5	"	8.0 "	1987
"	10	"	9.6 "	"
Ghost shrimp	10	"	24.9 "	Hurlburt (1986)
Dungeness crab	10	"	41.9 "	"
Mud shrimp	10	"	6.6 carb+naph	Chambers (1970)
Neried worms	"	"	9.2;8.1 "	"
Dungeness crab	"	"	5.6 "	"
Pacific oyster	10	day 0-30	no increase above bkg (0.01-0.02 carb+naph)	Sayce and Chambers (1970) "
Pacific oyster	10	day 0	0.02 carb+naph	Sayce (1970)
"	"	day 1	<0.04 "	"
"	"	day 3	<0.04 "	"

With the exception of oysters, concentrations of carbaryl in the range of 5 to 41.9 ppm have been measured in tideflat organisms within the first day of treatment. Sayce and Chambers data were from colorimetric analysis; the more recent data were by HPLC. Dr. William Roth, Washington Food and Drug Laboratory, Seattle, who directed the above analyses, has suggested mud on or in the organisms may have been responsible for the elevated concentrations (Roth, 1987, personal communication). Exposure of channel catfish (Ictalurus punctatus) to carbaryl via food and water resulted in a maximum accumulation of only 0.011 ppm "carbaryl and metabolites" (Korn, 1973). Carbaryl has an octanol/water partition coefficient of <100 which suggests it is not extremely bioaccumulative (EPA, 1986).

There are no recent data on the rate of decline of carbaryl or 1-naphthol concentrations in organisms beyond one day. Carbaryl concentrations in dead shrimp removed from treatment areas and held at Fisheries Willapa Shellfish Laboratory declined from 4.4 ppm to 0.4 ppm in one day, and were 0.2 ppm at four days (Creekman and Hurlburt, 1987).

Fisheries recently estimated (Hurlburt, 1987) that for the period 1984 to 1986, the average loss of harvestable male crab due to Sevin treatments was 1,068 individuals valued at $2,900. Potential enhancement due to planting bare ground with oysters was estimated to range from 6,500 to 52,000 harvestable crab/year over the same period. This enhancement potential was considered optimistic because it assumed all sprayed ground is bare. These figures were based on Fisheries post-treatment crab mortality data, a male-female ratio of 1:1, a crab density of 3 to $24/m^2$ on oyster beds, and recent UW estimates of natural mortality rates (Table 9) developed for the Corps of Engineers dredging project in Grays Harbor (Armstrong, 1987).

Table 9. Estimates of Dungeness crab survival rates (from Hurlburt 1987).

	Year Class				Survival to Harvest (0+ to 4+)
	0+	1+	2+	3+	
UW	5%	16%	38%	45%	0.14%
Fisheries*	5%	15%	45%	75%	0.25%

*Adjusted to allow for potential underestimate of older crab by UW sampling methods

UW Studies:

The UW began studying Dungeness crab populations in Grays Harbor in 1980-1981 as part of research for the Army Corps of Engineers dredging project. In 1983 the UW began a Sea Grant sponsored study in Grays Harbor with the primary objective being a comparison between estuarine and offshore crab populations; a limited intertidal survey of the abundance of juvenile crab on different types of substrates was also conducted for the Corps (Armstrong and Gunderson, 1985). Sea Grant sponsored crab population studies were expanded to Willapa Bay in 1985.

UW research on the impact of Sevin applications on Dungeness crab is limited to 1/4 square-meter quadrats, trawls, and live-box experiments done at three Willapa Bay tracts in 1986 for Ecology (Doty, et al., 1987 draft). The quadrat sampling entailed removing and sieving the top 3 to 5 cm of sediment to ensure that all YOY within the quadrat were retained. Doty (1987, personal communication) summarizes the results as follows:

1. Peak abundance of YOY crab was observed during July at the three sites.

2. Compared to the years from 1983 to 1985, density on settlement of YOY crab was lowest in 1986.

3. The density of YOY crab found in intertidal areas with cover of either shell or eelgrass was significantly higher than sand or mud samples. There were no apparent differences in crab density between shell and eelgrass, which may reflect the very sparse settlement in 1986.

4. Significant crab mortality was observed on the sites. Pre-spray densities ranged from 1 to 5 crab/m^2 (primarily YOY). Crab densities found in 24-hour post-treatment samples were 66 to 100 percent lower than those found before treatment, and the number of live crab observed in samples dropped to zero 24 hours after treatment. (Armstrong [1987] observed that UW estimates of crab killed were higher than Fisheries counts from visual transects.)

5. Post-treatment recolonization of intertidal sites was observed during August and September primarily in shell habitat and apparently are due to settlement and migration of crab onto the sites.

6. Subtidal 1+ juvenile mortalities in channels adjacent to the treatment areas appear to be low based on 24-hour post-treatment trawl and cage results. Mortality in trawls ranged from 0 to 2 percent. Mortality of crab (1+) held in cages in subtidal channels ranged from 0 to 1 percent.

7. Mortality of 1+ juvenile crab held in cages in drainage creeks on treatment sites was variable, ranging from 0 to 22 percent.

UW recommendations for improved assessment of impacts on Dungeness crab include use of control sites to compare normal population fluctuations, more effort in following plume impacts off-site during the first flood tide, and conducting trawl and cage surveys up to 48 hours after treatment to assess delayed mortality. In their opinion, entire bay estimates are needed to gage the impact of Sevin use on the Dungeness crab population (Doty, et al., 1987 draft).

o <u>What mortality is experienced by fish?</u>

Fisheries Studies:

A 1962 study by Fisheries on Sevin application in Grays Harbor reports but does not quantify the deaths of "blennies, gobies, and sticklebacks" following treatment of 5 acres at 10 lbs. per acre (Chambers, 1970). Fisheries is currently working up some data on fish mortalities observed during the 1986 post-treatment inspections. In general, low numbers of dead blennies, sticklebacks, shiner perch, gobies, sculpins and flatfish were encountered (Tufts, 1987, personal communication). Other information on fish mortality is limited to observations of Fisheries biologists over the course of past applications in Willapa Bay and Grays Harbor. The EIS summarizes these observations as follows:

> "The only observed fish mortalities have been of small fish which were trapped in shallow pools by the outgoing tide and directly exposed to Sevin during treatment. . . .WDF regularly observes small numbers of dead staghorn sculpin, eelpout, and, on rare occasion, juvenile lingcod on treated oyster tracts. In 1984 over 200 young lingcod were found on a single sprayed tract . . .In previous years, lingcod were observed only occasionally and then in limited numbers (less than 10 per tract). Because of their low frequency, fish mortalities have not been routinely recorded and the actual losses are unknown. . . .No dead fish have been observed on the tide following treatment."

Certain Willapa Bay fisherman claim sturgeon disappear when Sevin spraying starts. Fisheries has compared catch records with dates and locations of spray projects and found no correlation (Stone, 1987, personal communication).

Data on the subject of fish mortality are missing in three major areas:

1. The number of fish killed by direct exposure.

2. The potential for delayed mortality from ingesting contaminated organisms.

3. Use of the intertidal habitat by fishes, especially juveniles. In this regard, it is known that Willapa Bay and Grays Harbor serve as nursery grounds for juvenile chinook, coho, steelhead, and sea run cutthroat (Simenstad and Eggers, 1981; Army Corps of Engineers, 1976). The period of maximum residency for a number of baitfish species in Grays Harbor, and probably Willapa Bay, coincides with the July-August application period (Simenstad and Eggers, 1981). The EIS indicates juvenile coho are absent during the period of concern, but comments from the National Marine Fisheries Service, in the EIS, cite Fisheries data showing hatchery releases of coho to Willapa Bay tributaries have occurred during July and August.

Other Data:

Snow and Stewart (1963) observed dead blennies and cottids after a field treatment in Tillamook Bay.

Armstrong and Millemann (1974) counted eighty dead juvenile sole (Parophrys vetulus) on experimental plots in Yaquina Bay.

Buchanan, et al. (1985) express concern about potential predator-prey impacts on fishes. The importance of Corophium--an amphipod extremely sensitive to Sevin--in the diet of juvenile chinook was one such concern in Tillamook Bay (Bottom, 1982).

o Are birds adversely affected?

Fisheries Studies:

There have been no field investigations of this question in Willapa Bay or Grays Harbor. The EIS states that Fisheries biologists frequently see gulls, curlews, plovers, and turnstones feeding on recently sprayed tracts, but that no distressed birds have been observed.

Other Data:

There is a considerable amount of data showing that birds are not very sensitive to carbaryl. The EIS presents data from the literature which indicate an acute oral LD-50 in the range of 780 to 5000 mg of carbaryl per kg of body weight for various bird species.

Mount and Oehme (1981) reviewed the literature on chronic and sublethal effects of carbaryl to birds and concluded that numerous field and laboratory studies have found no effect on numbers, condition, or reproduction of birds.

o What are the potential ecological impacts of Sevin applications?

Attempts to answer this complex question have been limited to the conclusion in the EIS that "use of Sevin by the commercial oyster industry is not expected to cause significant impacts on the estuarine ecosystem when applied at current levels." The reasoning behind this statement was as follows:

1. "Sevin is not accumulated by any food chain component or transmitted to higher levels in the food chain."

2. "No chemically active radical group remains to contaminate the estuarine environment." (Persistence in sediment has not been determined.)

3. Only a small percentage of the total intertidal lands are treated annually; 0.8 percent in Willapa Bay and 0.3 percent

in Grays Harbor are the figures cited in the EIS. (This assumes that impacts do not extend beyond tract boundaries and that impacts are short-term; i.e., less than one year.)

RECOMMENDATIONS

Based on this review, I recommend the priorities for research on impacts of Sevin application to oyster beds in Willapa Bay and Grays Harbor should be as follows:

A. High-priority questions

- How long do carbaryl and 1-naphthol persist in the sediments?
- What concentrations of carbaryl and 1-naphthol in sediment are toxic to marine organisms?
- What are the effects on the abundance and diversity of infauna?
- What mortality is experienced by Dungeness crab and how does this affect the fishery?
- What mortality is experienced by fish?
- What are the potential ecological impacts of Sevin application?

Remarks: There are only short-term data on persistence and no data on sediment toxicity. Future sediment studies should incorporate a strong program to assure the quality of the data, include both off-site and subsurface samples, and analyze sufficient samples to assure some statistical confidence in the results. Toxicity data could be obtained relatively quickly with bioassays. Infauna studies (below) would also address these concerns.

The existing data on infauna are limited to a small, inconclusive data set. Future studies should be designed to include tidelands that have never been treated, tracts that have been treated historically, and tidelands subject to drift from treated tracts. The experimental design should be appropriate for determining the statistical significance of the results obtained. Cost of infauna studies could be reduced by limiting the study to selected crustacean species.

Limited pre-treatment population assessments by Fisheries and quadrat samples collected by the UW before and after spraying indicate a need for more detailed assessment of Dungeness crab mortalities. More data are needed to accurately assess the impact of Sevin applications on the crab fishery.

The only data on fish mortality are unpublished count data from post-treatment inspections. At a minimum, there is a need to assess the frequency of occurrence of important commercial or sport fish species in this habitat.

A subjective opinion on the question of ecological impacts could be obtained from experts in estuarine ecology following consideration of data from past and proposed research, coupled with an exercise mapping areas of Willapa Bay and Grays Harbor affected by oyster culture and Sevin application.

B. Medium-priority questions

- o How long do carbaryl and 1-naphthol persist in the water column?
- o What are the effects on the abundance and diversity of epifauna?

Remarks: Although the question of persistence in water has not been investigated thoroughly, the difficulty of tracking a block of contaminated water in a tidal environment is recognized. Occurrence of potentially toxic water concentrations of carbaryl and 1-naphthol has been documented both on- and off-site. One aspect of this question which might warrant additional investigation is the influence of wave action in resuspending contaminated sediments. In the absence of resuspension, tidal mixing probably dilutes water column concentrations of carbaryl relatively rapidly. A potential drawback in not improving this data base is that results of these types of measurements, coupled with existing toxicity data, tend to be less equivocal than assessments of biological impacts.

Epifauna studies are judged medium priority on the assumption that Dungeness crab and infauna receive adequate attention. If significant impacts are not found for these organisms, similar findings are likely for epifauna.

C. Low-priority questions

- o What concentrations of carbaryl and 1-naphthol in water are toxic to marine organisms?
- o Are birds adversely affected?

Remarks: There are ample data on acute toxicity of carbaryl and 1-naphthol in water. If there is a route of long-term exposure to carbaryl in Willapa Bay and Grays Harbor, it is more likely through sediment than the water column.

Broader ecological questions aside, results of extensive laboratory and field studies indicate birds are probably not affected significantly.

AJ:cp
Attachments

cc: Marc Horton
Dick Cunningham
Mike Palko
Norm Glenn
Marvin Vialle
Eric Hurlburt

REFERENCES

Aly, O.M. and M.A. El-Dib, 1971. Studies on the persistence of some carbamate insecticides in the aquatic environment. - I. Hydrolysis of Sevin, Baygon, Pyrolan, and Dimetilan in waters. Water Res. 5:1191-1205

Anonymous, 1986. (draft) Water analysis. Wash. St. Dept. Fisheries. 13 pp.

Armstrong, D.A. and R.E. Millemann, 1974. Effects of the insecticide carbaryl on clams and some other intertidal mudflat animals. J. Fish. Res. Bd. Can. 31:466-469

Armstrong, D.A. and D.R. Gunderson, 1985. The role of estuaries in Dungeness crab early life history: a case study in Grays Harbor, Washington. Proc. Symp. Dungeness Crab Biology and Management. Alaska Sea Grant Rept. 85-3:145-170.

Armstrong, D.A., 1987. Oysters, burrowing shrimp and Sevin: the effect of a pesticide on Dungeness crab and estuarine communities. Univ. of Wash. School of Fisheries proposal to EPA.

Armstrong, D.A., T.C. Wainwright, J. Orensanz, D.A. Dinnel, and B.R. Dumbauld, 1987. Model of dredging impact on Dungeness crab in Grays Harbor, Washington for Army Corps of Engineers. FRI-UW-8702.

Army Corps of Engineers, 1975. Willapa River and Harbor Navigation Project - Washington. Draft Environmental Impact Statement.

Bottom, D., 1982. Use of carbaryl insecticide in Tillamook Bay. Oregon Dept. Fish and Wildlife memorandum.

Buchanan, D.V., D.L. Bottom, and D.A. Armstrong, 1985. The controversial use of the insecticide Sevin in Pacific Northwest estuaries: Its effects on Dungeness crab, Pacific oysters, and other species. in Proceedings of the Symposium on Dungeness Crab Biology and Management, Anchorage, Alaska. October 9-11, 1984. pp. 401-417

Buchanan, D.V., R.E. Millemann, and N.E. Stewart, 1970. Effects of the insecticide Sevin on various stages of the Dungeness crab, *Cancer magister*. J. Fish. Res. Bd. Can. 27:93-104

Butler, J.A., R.E. Millemann, and N.E. Stewart, 1968. Effects of the insecticide Sevin on survival and growth of the cockle clam, *Clinocardium nuttalli*. J. Fish. Res. Bd. Can. 25(8):1621-1635

Butler, P.A., 1962. Effects on commercial fisheries. in Effects of Pesticides on Fish and Wildlife. A Review of Investigations During 1966. pp. 20-24; 42-44. U.S. Fish and Wildlife Serv. Circ. 143

Chambers, J.S., 1970. Investigation of chemical control of ghost shrimp on oyster grounds. in R. Westly (ed.) Ghost Shrimp Control Experiments with Sevin 1960-1968. Wash. St. Dept. Fisheries. Tech. Rept. 1. pp. 25-62

Creekman, L.L. and E.F. Hurlburt, 1987. Control of burrowing shrimp on oyster beds in Willapa Bay and Grays Harbor, 1985. Wash. St. Dept. Fisheries. Special Shellfish Report No. 3. 27 pp.

Davis, H.C., 1961. Effects of some pesticides on eggs and larvae of oysters (Crassostrea virginiica) and clams (Venus mercenaria). U.S. Fish and Wildlife Service. Commercial Fisheries Review 23:8-23

Doty, D.C., D.A. Armstrong, and B.R. Dumbault, 1987. The impact of the insecticide Sevin to local populations of Dungeness crab (Cancer magister) in Willapa Bay, 1986. Univ. Wash., School of Fisheries. Draft rept. for Ecology. 34 pp.

Eichelberger, J.W. and J.J. Lichtenberg, 1971. Persistence of pesticides in river water. Environ. Sci. Technol. 5:541-544

EPA, 1984a. Guidance on the registration of pesticide products containing carbaryl as the active ingredient. Office of Pesticide Programs, Wash. D.C.

EPA, 1984b. Chemical information fact sheet for carbaryl. 10 pp.

EPA, 1986. Draft work/QA project plan for the bioaccumulation study. Monitoring and Support Division, Washington DC.

Hurlburt, E.F. (ed.), 1986. Control of burrowing shrimp on oyster beds in Willapa Bay and Grays Harbor, 1984. Wash. St. Dept. Fish. Spec. Shellfish Rept. No. 2. 40 pp.

Hurlburt, E., 1987. Assessment of Dungeness crab kill from Sevin spraying. Fisheries memorandum to R. Westley. 3 pp.

Hurlburt, E., 1987. Wash. St. Dept. Fisheries, Olympia, WA. personal communication.

Kanazawa, J., 1975. Bull. Environ. Contam. Toxicol. 14:346

Karinen, J.F., J.G. Lamberton, N.E. Stewart, and L.C. Terriere, 1967. Persistence of carbaryl in the marine estuarine environment. Chemical and biological stability in aquarium systems. J. Agr. Food Chem. 15:148-156

Korn, S., 1973. The uptake and persistence of carbaryl in channel catfish. Trans. Am. Fish. Soc. 1:137-138.

Lamberton, J.G. and R.R. Claeys, 1970. Degradation of 1-naphthol in seawater. J. Agr. Food Chem. 18(1):92-96

Lingaraja, T. and V.K. Venugopalan, 1979. A simple method for the micro-estimation of carbaryl. Centre of Advanced Study in Marine Biology, Annamalai University, India.

Liu, D., K. Thompson, and W.M.J. Strachan, 1981. Biodegradation of carbaryl in simulated aquatic environment. Bull. Environ. Contam. Toxicol. 27:412-417

Mount, M.E. and F.W. Oehme, 1981. Carbaryl, a literature review. Residue Rev. V. 80. 64 pp.

Mulla, M.S., 1960. Longevity of insecticides in soil as tested against the eye gnat Hippelates collusor. Musquito News 20:376-379.

National Academy of Sciences, 1973. Water quality criteria, 1972. EPA-R3-73-033

Oregon Department of Fish and Wildlife, 1982. Review of application for a permit to use carbaryl insecticide for control of mud and ghost shrimp on certain oyster grounds in Tillamook Bay. Staff Rept. to the Oregon Fish and Wildlife Commission, Portland, Oregon.

Owens, J., 1987. Laucks Testing Laboratories, Seattle WA. personal communication.

Post, G. and T.R. Schroeder, 1971. The toxicity of four insecticides to four salmonid species. Bull. Environ. Contam. Toxicol. 6(2):144-155

Rieck, B., 1987. EPA/WDOE Environmental Laboratory, Manchester, WA. personal communication.

Riniker, A.B., 1986. Director, Wash. St. Dept. Ecology, letter to W.R., Wilkerson, director, Wash. St. Dept. Fisheries.

Roth, W., 1987. Wash. Food and Drug Laboratory, Seattle, WA. personal communication.

Sayce, C.S., 1970. The uptake of Sevin by Pacific oysters and bottom muds. in P. Westley (ed.) Ghost shrimp control experiments with Sevin 1960-1968. Wash. St. Dept. Fisheries Tech. Rept. 1 pp. 13-21

Sikka, H.C., S. Miyazaki, and R.S. Lynch, 1975. Degradation of carbaryl and 1-naphthol by marine organisms. Bull. Environ. Contam. Toxicol. 13(6):666-672

Simenstad, C.A. and D.M. Eggers, 1981. Juvenile salmonid and baitfish distribution, abundance, and prey resources in selected areas of Grays Harbor, Washington. Fish. Research Inst., Univ. of Wash. 205 pp.

Snow, C.D. and N.E. Stewart, 1963. Treatement of Tillamook Bay oyster beds with MGS-90 (Sevin). Fish. Comm. of Oregon. 8 pp.

Stanley, J.G. and J.G. Trial, 1980. Bull. Environ. Contam. Toxicol. 25:771

Stewart, M.E., R.E. Millemann, and W.P. Breese, 1967. Acute toxicity of the insecticide Sevin and its hydrolytic product 1-naphthol to some marine organisms. Trans. Am. Fish. Soc. 96:25-30

Stone, D., 1987. Wash. St. Dept. Fisheries, Coastal Field Station, Montesano, WA. personal communication.

Tagatz, M.E., J.M. Ivey, H.K. Lehman, and J.L. Oglesby, 1979. Effects of Sevin on development of experimental estuarine communities. J. Toxicol. Environ. Health 5:643-651

Tarr, M., 1987. Wash. St. Dept. Fisheries Point Whitney Shellfish Laboratory, Brinnon, WA. personal communication.

Tufts, D.F., 1983. Affidavit. Wash. St. Dept. Fisheries, Willapa Shellfish Laboratory.

Tufts, D.F., 1987. Washington St. Dept. Fisheries, Willapa Shellfish Laboratory, personal communication.

Tufts, D.F., 1987. Washington St. Dept. Fisheries, Willapa Shellfish Laboratory, unpubl. data.

Ukeles, R., 1962. Growth of pure cultures of marine phytoplankton in the presence of toxicants. Appl. Microbiol. 10:532-537

Washington State Departments of Fisheries and Ecology, 1985. Use of the insecticide Sevin to control ghost and mud shrimp on oyster beds in Willapa Bay and Grays Harbor. Final Environmental Impact Statement. 40 pp.

Weis, P. and J.F. Weis, 1974. Cardiac malformations and other effects due to insecticides in embryos in killifish. Teratology 10:263.

Weis, P. and J.F. Weis, 1976. Optical malformations induced by insecticides in embryos of the Atlantic silverside. Fish. Bull. 74:208.

APPENDIX

Conditions for Application of SEVIN (1987)

1. SEVIN shall be used for burrowing shrimp control. Applications shall follow all label requirements and all appropriate requirements of the Department of Ecology and other agencies. A company representative shall be present at the site at the time of treatment.

2. SEVIN application shall not exceed 7.5 pounds active ingredient per acre treated.

3. Treatment is only authorized after the Department has inspected the proposed site and approved it for treatment.

4. SEVIN shall only be applied to those beds which are uncovered by the outgoing tide. No SEVIN application shall occur later than one-half hour after low tide.

5. No aerial application shall occur within 200 feet of sloughs, channels, or market oysters. No hand application shall occur within 50 feet of sloughs, channels, or market oysters.

6. All tracts to be sprayed must be marked and flagged during application.

7. No aerial application shall be allowed when the wind velocity at the treatment site exceeds 10 miles per hour.

8. The permit holder for himself, agents, contractors, heirs, executors, administrators, successors, and assigns; by acceptance of this permit, agrees to full performance of all conditions of this permit. Failure to comply with any condition of this permit will subject the permit to revocation. The permit holder will be liable for any loss or damage to public fish resources or habitat caused by his failure to abide by the terms or conditions of this permit.

9. The Department of Fisheries reserves the right to make additional restrictions or conditions to this permit, including delay, suspension, or termination of the privileges of this permit, if deemed necessary for the protection of fishery resources.

10. The permit holder agrees to indemnify and save harmless the State, Department, Director and all officers and employees of the State, from all claims, suits, or actions brought for injuries or death of any person or damages to property resulting from the project approved by this permit or in consequence of any negligence caused in whole or in part by any act or omission of the permit holder, his agents, contractors, or employees during the performance of the project authorized by this permit.

11. Nothing in this permit shall be construed to mean that the permittee is exempt from compliance with any valid law or regulation of any government agency including permitting or licensing requirements.