Exxon Valdez Oil Spill
Restoration Project Final Report

Restoration Monitoring of Harlequin Ducks (*Histrionicus histrionicus*) in Prince William Sound and Afognak Island, Alaska

Restoration Project 93033-1
Final Report

This report has been produced by the Alaska Department of Fish and Game taking into consideration comments made in review of earlier drafts. In the interest in making this information available to the public in a timely manner, however, this present version of the report has not been reviewed by the Chief Scientist for the *Exxon Valdez* Trustee Council and, therefore, does not necessarily reflect the position of the Trustee Council.

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Study History: This project, conducted during 1993, continued the research begun in NRDA Bird Study No. 11 (Patten et al. 2000) to investigate impacts of the *Exxon Valdez* oil spill (EVOS) on sea ducks and the status and productivity of harlequin ducks. The 1993 monitoring program did not include breeding season boat surveys, but was composed of four task areas: (1) harlequin ducks were collected in eastern and western Prince William Sound (PWS) during spring to document evidence of continuing exposure to oil and investigate potential effects on reproductive physiology; (2) boat surveys were focused on post-breeding harlequin ducks in PWS because of indicated declines in molting birds in the oil spill area during 1991-1992; (3) resources were added to the project to conduct a harlequin duck brood survey in western PWS because of low production observed in 1990-1992; and (4) an assessment of harlequin duck use and habitat conditions on Afognak Island was included to support potential land acquisitions by the EVOS Trustee Council.

Information on Afognak Island harlequin ducks and an evaluation of their habitats was summarized and provided to ADFG Habitat and Restoration Division in late 1993 for inclusion in the EVOS land acquisition program. Work began on a draft final report in early 1994, but by June, all of the original staff, including the principal investigator, had left the project. Since then, this final report has been redrafted several times and peer-reviewed. Previous drafts were extensively edited by the ADFG Waterfowl Program staff for format and style, and to verify and expand original data presentations. This report describes only the harlequin duck survey tasks. Results of 1993 harlequin duck collections, food habits, contaminant sampling, and physiological studies (histopathology and blood chemistry) are presented under separate cover (Restoration Project 93033-2), including a contract report by Dr. D. Michael Fry, University of California, Davis.

Abstract: We monitored densities of molting harlequin ducks and broods in the oil spill area of western Prince William Sound (WPWS) and in the non-oiled eastern area (EPWS) during July and August 1993. The shoreline density indices of molting harlequin ducks in WPWS was consistently lower than those in EPWS, at 1.29/km in 1991, 0.92/km in 1992, and 1.34/km in 1993. Density indices in EPWS were relatively stable, averaging 2.04/km, but were 1.6, 2.0 and 1.6 times greater than in WPWS during 1991-1993. These data indicate that the densities of molting harlequin ducks were greater in the unoiled portions of PWS, suggesting differential use because of oil effects or regional ecological differences. Differences in survey timing and coverage among years contributed an unknown margin of error in comparisons across years and regions. The shoreline density indices of broods in WPWS decreased 69% from 0.74/100 km in 1991 to 0.23/100 km in 1993. Densities of broods in EPWS averaged 2.02/100 km and were (respectively) 3.9, 7.1 and 7.8 times greater than in WPWS during 1991-1993, indicating that productivity declined in WPWS. The lack of pre-spill baseline population data and habitat differences between WPWS and EPWS preclude distinguishing oil spill effects from other ecological or demographic variation.

Key Words: Afognak Island, *Exxon Valdez* oil spill, Harlequin ducks, *Histrionicus histrionicus*, Prince William Sound, restoration.

Project Data: Project data are recorded on paper (notebooks and forms), maps, and electronic compilations. Principal data sets include: (1) boat survey data by date and location, (2) extensive descriptive records of potential breeding streams on north Afognak Island, and (3) original and compiled records of oiling conditions and bird observations by numbered beach segment/stream and date. All data and materials are supervised and located with the Waterfowl Coordinator, Alaska Department of Fish and Game, 525 West 67th Avenue, Anchorage, Alaska 99518. Contact the Coordinator by mail, telephone (907) 267-2206, or facsimile (907) 267-2859. All records not protected for litigation purposes are in the public domain and available under standard access procedures. Copies of many records also are found in the State of Alaska Archives (Juneau, Alaska) and Alaska Resources Library and Information Services (Anchorage, Alaska).

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EXECUTIVE SUMMARY

The goal of this project was to determine whether harlequin ducks were recovering from an apparent population decline and poor reproduction following the *Exxon Valdez* oil spill. We conducted field work both in the oil spill area of western Prince William Sound, and in the eastern area of the sound not directly impacted by EVOS. Although not functionally a "control" area, eastern Prince William Sound provided some data for comparisons between populations in oiled and non-oiled regions.

We conducted shoreline surveys to derive a shoreline density index (ducks per linear km of shoreline surveyed), location, and distribution of harlequin ducks within coastal habitats. The shoreline density indices of molting harlequin ducks varied annually in the oil spill area, from 1.29 /km in 1991 to 0.92/km in 1992, and 1.34/km in 1993. The density of molting harlequins in the non-oiled study area has been at least 1.6 times greater than in the oil spill area each year.

During the molt, harlequin ducks did not avoid habitat that had been initially classified as receiving heavy to light impact from oil. Approximately 58% of harlequins observed in 1993 occupied initially-oiled habitat. Fifteen percent of harlequin ducks observed during molt surveys were at or near mussel beds containing residual oil. Molting harlequins are obligated to feed where they become flightless, indicating the potential for continued exposure.

Shoreline density indices of harlequin duck broods in the oil spill area decreased from 0.74/100 km in 1991 to 0.23/100 km in 1993, while brood densities in the eastern study area were 3-9 times greater. The difference in the brood density indices between oiled and non-oiled study areas were substantially greater in 1992 and 1993 than in 1991, suggesting declining productivity in the oil spill area.

We conducted habitat assessment of streams potentially used by harlequin ducks breeding on northern Afognak Island. Seven of 12 streams investigated on Afognak had medium to high potential for use by harlequin ducks. Comparison of habitat variables from stream mouths indicated that streams measured on Afognak had significantly smaller estuaries and narrower widths than streams of eastern Prince William Sound. There was, however, no difference in discharge, which was previously determined to be the most important variable in discerning breeding from non-breeding streams in the eastern study area (Crowley 1993).

We suggest that direct mortality of females, combined with sublethal effects of oil toxicity on reproductive physiology and survival may have caused low productivity and lower densities of molting harlequin ducks in WPWS. However, several factors preclude a cause-and-effect assessment of oil impacts: (1) the lack of pre-spill baseline data on population size and productivity, (2) habitat differences between the oil spill area and eastern study area which were not quantified, and (3) differences in survey timing and coverage among years.

INTRODUCTION

Harlequin ducks (*Histrionicus histrionicus*) occur year-round in Prince William Sound and the Afognak area of the Kodiak Archipelago, where they feed and live in the intertidal and shallow subtidal zones. Harlequin duck populations in these areas include both residents and non-resident migrants (Isleib and Kessel 1973; Hogan 1980). Resident harlequins breed along forested streams within a few kilometers of saltwater, molt in secluded bays, lagoons or exposed coastlines, and roost on nearshore rocks. Broods are found with hens on saltwater in late summer. Non-resident harlequin ducks wintering on the south coast of Alaska arrive in October and depart in May. Harlequin ducks tend to return to the same breeding and wintering areas year after year (Breault and Savard 1991). Harlequin ducks are distributed throughout Prince William Sound, including the *Exxon Valdez* oil spill area, with broods commonly observed in shoreline habitats (Isleib and Kessel 1973; Oakley and Kuletz 1979; Dzinbal 1982; Isleib pers. comm.; Holbrook pers. comm.).

Patten et al. (2000) reported low productivity of harlequin ducks in the oil spill area, and suggested a possible chronic effect of petroleum exposure through contaminated intertidal food (Goldberg 1975; Shaw et al. 1976; Karinen and Babcock 1991; Babcock et al. 1993). Accumulation in the food chain may result in the uptake of petroleum hydrocarbons by harlequin ducks over a long period. Studies of seabirds indicate that ingestion of low doses of petroleum can result in failure to reproduce (Morant et al. 1981; Fry et al. 1986; Fry and Addiego 1988; Butler et al. 1988). Birds fed single doses of petroleum oils produced eggs with altered yolk structure and reduced hatchability (Grau et al. 1977). Patten et al. (2000) found contaminated food in some harlequin crops collected in the oil spill area.

Because reproductive decline can severely deplete a local population of harlequin ducks, it is important to understand what factors are responsible for limiting reproduction. Given the low level of breeding activity and the suspected high degree of site fidelity of harlequin ducks, we cannot assume that the population in oil- impacted (oiled) areas will return to pre-spill levels. The population of harlequin ducks may continue to decline because of a lack of recruitment and limited immigration. It is necessary to continue monitoring both population size and productivity.

Harlequin ducks inhabit the intertidal zone year-round and could serve as an indicator of continued oil exposure of the intertidal community. Harlequin ducks nest in upland old-growth forests, forage and breed in estuaries and freshwater streams, and molt and overwinter in coastal intertidal communities. Research on harlequin ducks has potential to contribute to an ecosystem approach toward resource management. The study of habitat requirements of breeding harlequin ducks has provided information for habitat acquisition and mitigation measures, protection of non-Federal lands, and other restoration actions. The goal of this project was to monitor status and productivity of harlequin ducks in Prince William Sound and continue investigating causes of decline.

OBJECTIVES

A. To continue monitoring productivity of harlequin ducks in oiled and unoiled areas of Prince William Sound by shoreline boat surveys. Compare data from 1993 surveys to previous data to determine whether harlequin ducks are recovering from their reproductive and population decline following the oil spill.

B. To characterize streams potentially used by harlequin ducks breeding on Afognak Island by boat survey and comparing known breeding streams in eastern Prince William Sound to streams on Afognak Island.

Original objectives of Project 93033, on histopathology and toxicology, are addressed under a separate cover (Project 93033-2), including a contract report by Dr. D. Michael Fry, University of California-Davis.

METHODS

STUDY AREA

The study area for Project 93033-1 consisted of three broad regions: those areas of western Prince William Sound and northern Afognak Island included within the *Exxon Valdez* oil spill area, and non-exposed (unoiled) area of eastern Prince William Sound (Figures 1 and 2). General descriptions of the region and sea duck habitats are found in Islieb and Kessel (1973). The oil spill study area of western Prince William Sound (WPWS) included nearshore rocks, bays, lagoons and stream mouths on the mainland from Applegate Island in Port Nellie Juan south to Bainbridge Island. WPWS extended east to Hanning Bay and MacLeod Harbors on Montague Island, to Green Island and north to Perry Island and the Naked Island group. The study area also included Chenega, Knight, Evans, Elrington, Latouche Islands. Eastern Prince William Sound (EPWS), extending south and east from Valdez Arm to Cordova, was not directly impacted by the oil spill (Figure 1).

The study area of northern Afognak Island included streams and coastline from Bluefox Bay on Shuyak Straits east to Phoenix Bay, encompassing Redfox and Perenosa Bays (Figure 2). A field crew assessed stream habitat for potential use by breeding harlequins on northern Afognak Island during the first week of June from Port Williams Lodge on Shuyak Straits.

POPULATION MONITORING

We conducted shoreline surveys to determine location and distribution of harlequin ducks within coastal habitats. Surveys were conducted by 2 - 3 observers aboard a skiff (5 - 7 m in length) at a distance of 5-50 m from shore, around islands, exposed rocks, and into embayments, lagoons and stream deltas. We used low speeds (0-10 km/hr) when searching for harlequin ducks in shoals and emergent rocky habitat. Higher speeds (up to 30 km/hr) were used when searching near-shore, deep water habitat not generally used by molting harlequin ducks. We avoided surveying when weather and seas limited visibility. When harlequin ducks were encountered the engine was turned off and the skiff was allowed to drift quietly toward the flock.

Harlequin ducks were counted and classified to sex when possible using 10x binoculars. Harlequin ducks exhibit sexual dimorphism, including in body size. Adult females are approximately 85% the size of adult males by weight (Bellrose, 1980, Crowley and Patten 1996). Molting males appear larger and darker than females. Males appear predominately black or dark brown, adult males have white wing markings, subadult males have mottled bellies. Females are lighter brown, have less distinct face patches, no white wing marking, and have mottled, cream-colored bellies. The dark colored heads and distinctive face patch of males were the most reliable indicators in separating molting males from females.

Surveys in EPWS and WPWS were conducted simultaneously, although WPWS surveys required more time to complete because of greater distances covered, and generally poorer weather conditions. We derived a shoreline density index (SDI = number of ducks per km of shoreline surveyed) of harlequins for comparison of study areas and years.

Selection of survey areas was prioritized first on covering areas surveyed in previous years (particularly where harlequins were observed), then on addition of coverage where harlequins might be present (i.e., shallow sloping beaches rather than steep bluffs and cliffs). No effort was made to randomize coverage, but rather to maximize coverage and harlequins counted.

We recorded habitat types (nearshore rocks, bays and lagoons, stream mouths and mussel beds) used by molting harlequin ducks (molters). Areas surveyed and sites occupied by harlequin ducks in WPWS were identified by a system of numbered beach segments used by clean-up crews (ADEC 1989). This segment system provided a history of initial oiling conditions (heavy, moderate, light, very light, non-oiled) and clean-up activities within habitats used by harlequin ducks. Because mussel beds retained more oil relative to the surrounding environment through 1993 (Babcock et al. 1993), and mussels are a localized food source important to harlequins (Vermeer 1983, Patten et al. (2000) the proximity of molting flocks to mussel beds was recorded. Distances of molting harlequins to mussel beds were classified as within or not within easy swimming distance (approximately 200 m) of flightless ducks.

PRODUCTIVITY MONITORING

We recorded broods of harlequins encountered during boat surveys. Ducklings were classified by plumage characteristics into one of seven age classes: Ia - III (Gollop and Marshall 1954, Wallen 1987) to preclude misidentification with molting females. The following criteria for identification of broods were compiled from previous years observations of broods, particularly from EPWS where broods were more commonly observed from hatchling to near-fledging age classes.

Harlequin ducklings observed in July and early August were distinguishable from females by smaller size, presence of down, and broody behavior. As ducklings approached adult size (class III), they became more difficult to differentiate from adult females. Upon scrutiny with 10x binoculars, remnant down on head or back was sometimes apparent on ducklings. Ducklings also had darker faces and bills than females. The large face patch on ducklings was grayish instead of white, and body plumage appeared slightly lighter than that of females. Ducklings had rounded, vascularized wing-tips compared to molting adults, which had pointed wing tips when primary feathers were molted or not fully grown. For adult-sized ducklings, approaching slowly by boat helped distinguish broods from mixed flocks of molters. When less than 30 m from suspected broods and using 10x binoculars, behavioral observations helped distinguish class IIc and III ducklings from females. Molting or flight-capable adults swam rapidly or flew away, while ducklings followed the female, responded to her calls, and were unable to escape by rapid swimming. We believe that these criteria were fairly reliable through class IIc ducklings. However, small flocks of molting females were sometimes indistinguishable from class III broods. When in doubt, we classified these groups as molting females rather than as broods.

Brood surveys were best conducted during the last week of July and first 2 weeks of August, after hatching was essentially complete and before fledging began (Crowley 1993) because fledged ducklings were nearly impossible to distinguish from females (Cassirer and Groves 1992). SDIs of broods (number of broods/100 km) were compared between study areas and survey years.

Assessment of Northern Afognak Island

We assessed stream habitats and adjacent uplands on northern Afognak Island for use by harlequin ducks and potential suitability for breeding. The study area was selected to develop information on potential habitat values for harlequin ducks, to address interest by the EVOS Trustee Council in prospective land acquisitions. Boat surveys, as described previously, were conducted in the bays and estuaries of northern Afognak (Figure 2) during early June to detect harlequin ducks in and near streams in the study area.

The presence of harlequin ducks and detailed habitat information was documented in accordance with standard operating procedures (Appendix 1) adapted for this project from Bird Study 11 (Patten et al. 2000) and Restoration Project 71 (Crowley and Patten 1996). Specific descriptive and quantitative data fields were developed for harlequin duck breeding streams and nesting habitat from Cassirer and Groves (1991) and Crowley (1991); and for general stream characteristics from Oswood and Barber (1982).

Based on habitat characteristics and presence or absence of breeding harlequins (i.e., pairs in early June near the mouth of streams), each study stream was rated in the field on a subjective scale of 1 to 5. Streams having an apparent, high probability of use by breeding harlequins were scored 5, and those of low probability of use were rated 1.

Analyses of habitat variables collected from stream mouths, drainage networks and basins were described by Crowley (1993). These variables were used to compare the streams surveyed on

Afognak to streams investigated in EPWS using Mann-Whitney-Wilcoxin Z tests and principal components analysis. Additional comparisons were done between probable breeding streams (those rated 3 - 5) on Afognak to streams known to be used by breeding harlequins in EPWS (Crowley 1993).

Information on anadromous fish streams also was obtained from three other sources: (1) the Anadromous Waters Catalog (ADFG 1990); (2) stream habitat assessment by Kuwada and Sundet (1993); and (3) a summary of streams and riparian habitat profiled by the USFS (C. Sanner ADOTPF, pers. comm.).

RESULTS

Harlequin ducks in Prince William Sound were observed at nearshore rocks (unvegetated, emergent rocks a short distant from shore) or along rocky beaches with intertidal islands, reefs and bedrock outcroppings. Harlequin ducks roosted on rocky outcrops, emergent rocks and gravel beaches and fed in the surrounding intertidal areas. Harlequins were more likely observed along shallow-sloping beaches (regardless of beach composition), than along steep, rocky cliffs and bluffs: surveys were thus focused on the former.

POPULATION MONITORING

Table 1 shows a comparison of summer survey coverage in WPWS among the three years 1991-1993. In 1993, harlequin duck surveys were conducted over 1,296 km in WPWS during July 5-August 26 (Figure 3). Most of this survey was conducted later than surveys in 1991 and 1992. We observed 916 harlequin ducks along islands, bays and the mainland coast (Tables 2 and 3) of which 761 were classified by association with specific habitat types and shoreline oiling history. The total number of harlequins was lower than in 1992, but higher than in 1991 (Table 3). The numbers and shoreline density indices (SDI) of harlequin ducks were substantially higher in EPWS than in WPWS each year (Table 3), with the greatest difference in 1992 (1.85 /km vs. 0.92/km). In 1993, males comprised a larger proportion of flocks in WPWS than in EPWS.

Approximately 200 individuals, or 26% of molting harlequins in WPWS, were concentrated near Channel Island (GR004) in WPWS on the southeastern periphery of the oil spill (Table 2). Another large group of flightless harlequins (106) was nearby at an oiled segment on SW Green Island (GR300A). A third group of molting harlequins (58) was located at beach segment WH502 in lightly oiled Whale Bay in southern WPWS. Thirty-five molting harlequins and one brood of six ducklings were present in the estuary of Hanning Creek (ASC# 227-10-17110). The first harlequins observed to regain flight after molt were recorded on August 7.

More harlequin ducks were recorded around nearshore rocks (47%) than in other habitat types (Table 4). Most of these harlequins were in habitats with light to no oiling. Approximately 58% percent of harlequins observed in 1993 were located on oiled shoreline segments, including 15% on heavily or moderately oiled areas, potentially increasing their exposure to oil. Eighteen percent of harlequins were found on mussel beds; 15% were recorded on or near mussel beds still containing residual oil (Babcock et al. 1993). Eighty-three percent of mussel beds occupied by harlequin ducks in 1993 contained residual oil (Babcock et al. 1993).

We found further evidence that harlequins did not avoid oiled habitat by calculating SDIs from only those beach segments occupied by harlequins. Survey segment densities of harlequins were substantially higher along heavily to lightly oiled beach segments than those along unoiled segments, indicating that harlequins do not avoid oiled sites during the molt (Table 5). Although we did not attempt to compare habitat use versus availability, these data indicate the potential for continued exposure to residual oil.

Productivity Monitoring

We observed a total 14 harlequin duck broods (11 in EPWS and 3 in WPWS) along shoreline habitat, usually in or near stream estuaries in 1993 (Table 6).

Eastern Prince William Sound. During 1993, 620 km of shoreline were surveyed for broods in EPWS (see Crowley and Patten 1996) and 11 broods were recorded (Table 6). Broods were usually observed at or near stream mouths in EPWS in 1993. At least 10 streams in EPWS were used by harlequin ducks for breeding. Three of the broods were found along rocky points or nearshore rocks away from stream estuaries. Two of these three broods were on the west side of Bligh Island, 10 km from the nearest anadromous fish stream (ADFG 1990; Crowley and Patten 1996).

Western Prince William Sound. We searched 1,296 km of coastline in WPWS during 1993 (Table 7), observing three broods during this survey (Tables 6 and 7; Figure 3). Two broods were recorded in bays where oiling was minor and confined to headlands. A brood of six ducklings accompanied by a female was found on August 5 in the lower intertidal zone of a sandy estuary at the mouth of Hanning Creek on SW Montague Island. A second brood of one duckling, accompanied by a female and five molting males, was recorded on August 24 at West Twin Bay on Perry Island in northern WPWS. The duckling was observed along a low rocky shoreline with nearshore rocks, within 500 m of a grassy islet. No large streams were in the vicinity. One small, lake-fed stream with spawning pink salmon (ASC # 222-30-12930), however, was located at the south end of West Twin Bay, 1.5 km distant. A third brood (6 ducklings) was observed on August 26 along a rocky shoreline in a lightly oiled segment (EW900) between Jackpot and Ewan Bays in Dangerous Passage in southern WPWS. This brood was accompanied by a female and an adult male.

Productivity Indices

The SDI of broods in EPWS during 1993 was 1.8 broods/100 km (Table 3) and mean brood size was 2.18 (n = 11, SD = 1.27). In contrast, the SDI in WPWS was 0.23 broods/100 km and mean brood size was 4.33 (n = 3, SD = 2.36).

Assessment of Northern Afognak Island

Coastal harlequin duck habitats on Afognak were surveyed June 2-8, 1993. Summary descriptions of 12 Afognak streams are shown in Table 8, and primary measurements are listed in Table 9; detailed narrative descriptions are in Appendix 2. Seven streams had medium to high potential for use by breeding harlequin ducks (Table 10). Harlequins were observed in Bluefox Bay (55), near Redfox Bay (26), near the mouths of Little Waterfall Creek (74) and West Delphin Bay Creek (1 pair), in the estuaries of Shadow Creek (6) and Pauls-Laura Creek (79), and 5 harlequins were seen flying up Pauls-Laura Creek.

Comparison of habitat variables from all stream mouths indicated that streams measured on Afognak had significantly smaller estuaries ($p = 0.014$) and narrower widths ($p = 0.012$) than streams of EPWS (Table 11). There was, however, no significant difference in discharge ($p = 0.637$), the most important variable in discerning breeding from non-breeding streams in EPWS (Crowley 1993). There were no significant differences in width of riparian zone, channel slope and average sideslope at stream mouths. When 7 probable breeding streams on Afognak (Table 12) were selectively compared to 24 known breeding streams of EPWS, no significant differences were apparent in stream mouth variables.

Drainage network and basin measurements of streams on northern Afognak and EPWS (Table 13) were not significantly different with respect to size (area, perimeter, channel length and frequency). Measurements of gradient and relief, however, were significantly lower on Afognak, and there was a greater number of lakes on Afognak streams (Tables 13). Selective comparisons of basins and drainage networks of only verified breeding streams from EPWS and probable breeding streams from Afognak indicated no significant differences, except that basin shape was slightly less circular for streams of Afognak (Table 14).

Principal components analysis of all stream variables indicated that Afognak streams were similar in size to those of EPWS, but Afognak streams were of lower gradient. The first principal component (PC1) was weighted primarily with area (correlation coefficient 0.9672), perimeter (0.9595), channel length (0.9203), discharge (0.8488), and channel frequency (0.8013). The second principal component was weighted by basin relief (0.8052), mean basin gradient (0.7891), and channel gradient (0.6882). A plot of PC1 versus PC2 (Figure 4) placed 8 of the Afognak streams high on the PC1 axis (a function of stream size) with breeding streams of EPWS, but low on the PC2 axis (function of gradient and relief). PC3 was weighted by stream density (0.9020), which was similar between stream groups. The first three principal components explained 70% of the variation in the data.

Portions of this information were provided as part of an ADFG habitat assessment for land acquisitions (Kuwada and Sundet 1993) and published by the *Exxon Valdez* Oil Spill Restoration Team, Habitat Protection Work Group (1993). The latter publication also provided site-specific information of harlequin duck use of lands considered for acquisition on the Kenai Peninsula, EPWS, and WPWS.

DISCUSSION

POPULATION MONITORING

Survey dates (Table 3) and shoreline coverage (Table 1, Figure 3) differed somewhat between study areas and years. The SDIs of molting harlequin ducks were greater in EPWS than in WPWS each year of study (Figure 5). During 1991, 1992, and 1993 the SDI of molting ducks was (respectively) 1.6, 2.0, and 1.6 times greater in EPWS than in WPWS.

The progressive build-up in numbers of harlequins during our molt survey period could have biased survey results. Areas surveyed early would tend to have fewer ducks than those surveyed later in the molt. The number of harlequin males increased from our spring surveys (1991, 1992) to mid-July surveys (Patten et al. 2000), and in surveys conducted by the USFWS in June and August 1990 (Klosiewski and Laing 1993). These data indicate that harlequins return to Prince William Sound from other breeding areas. Late summer aggregations of harlequins have been noted elsewhere (Gabrielson and Lincoln 1959; Portenko 1981). Molting flocks on Channel and Green Islands may have gathered from nearby Montague Island, the Gulf Coast to the east, the Kenai Peninsula, or the Wrangell and Chugach Mountain drainages. We believe that an overall decline in molters occurred after the oil spill, but that differences in survey coverage and timing probably affected the accuracy of our estimates and year-to-year comparisons (e.g., molting harlequins may not have reached peak numbers on the early survey in 1991; more unoccupied shoreline may have been surveyed in 1992 and 1993).

Harlequins exhibit fidelity to molting areas, apparently returning year after year (Breault and Savard 1991). Molting harlequins are flightless; those inhabiting oiled areas are obligated to feed there. During this time of rapid primary feather growth in mid-summer, large demands are made on the energy reserves of molting ducks (Bellrose 1980). An abundant food supply is required to regain condition after breeding effort and supply energy for primary feather regrowth. Consequently, they tend to occupy molting sites that contain reliable, easily accessible food resources and protective microhabitats.

Habitat use patterns among harlequin ducks recorded in WPWS from 1991 through 1993, combined (Table 15), were similar to those of 1993 only (Table 5). Approximately 43, 77 and 58 percent of molting harlequins observed in WPWS in 1991, 1992, and 1993 respectively, were located on oiled habitat sites (nearshore rocks, bays and lagoons, stream mouths, and mussel beds). Sixty-six percent of the 3,154 molters (all years) in WPWS were located on oiled habitats, and their SDIs were higher on beach segments of heavy and moderate oiling conditions than light to unoiled conditions (Table 15). Use of oiled habitats by harlequin ducks for foraging and roosting indicated the potential for consumption of oiled prey items.

PRODUCTIVITY MONITORING

There has been a nearly complete lack of production by harlequin ducks in WPWS through 1993, in contrast to variable but presumably normal production in EPWS (Crowley and Patten 1996). The average SDI of broods in EPWS (1991-1993) was 5.4 times higher than in WPWS. In

1991, the SDI of broods in EPWS was 3.0 times greater than in WPWS (Figure 6), with 14 broods recorded in estuaries. In 1992, brood densities were lower throughout the Sound most probably a result of a late spring thaw that was expected to affect duck production in much of Alaska (Conant and Groves 1992). Regardless of these less favorable conditions, the brood SDI in 1992 was 7.1 times greater in EPWS than in the spill zone. In 1993, the brood SDI in EPWS was more than 7.7 times greater than in WPWS. The brood SDI in WPWS decreased by 69% from 1991 through 1993. These data suggest low productivity in WPWS versus EPWS, and declining production in WPWS.

Post-spill distribution (1989-1993) of harlequin broods, with respect to degree of initial oiling in WPWS, provides evidence of possible petroleum-related effects to harlequin duck reproduction (Figure 7). Since 1989, fourteen harlequin broods have been recorded in WPWS. Between 1989 and 1993, only four broods were observed along any oiled shoreline segments (Crafton Island, Johnson Bay, Whale Bay, Squire Island). In contrast, 10 broods were observed in lightly to very lightly or unoiled regions of WPWS. This may, however, be related to the amount of available habitat (i.e., more unoiled or lightly oiled brood-rearing habitat available).

No harlequin ducks broods were observed in the Naked Island group or Bay of Isles from 1989 through 1993. Although pre-spill brood observations were reported from these areas (Patten et al. 2000), their reliability (distinction of broods from molting groups) is unknown.

The disparity in harlequin duck productivity between EPWS and WPWS could be influenced by regional differences in quantity and suitability of breeding habitats. Crowley and Patten (1996) reported that WPWS streams tend to be shorter and have lower discharges than those in EPWS. Nevertheless, known harlequin breeding streams in WPWS include relatively short, steep streams with cascades, and limited anadromous fish habitat (e.g., Otter Creek in Bay of Isles on Knight Island) (Patten et al. (2000). Pink salmon, spawning largely at stream mouths and in estuarine zones, may provide adequate food for harlequins and their broods. We recorded harlequin broods in Johnson Bay, Whale Bay, and on Squire Island in WPWS, and on Bligh Island in EPWS where streams are absent or of low discharge.

In speculation, the relatively small streams in WPWS may receive limited use for nesting, and, combined with the relatively low breeding propensity of harlequins, may not be used annually even under ideal conditions. In contrast, the larger streams in EPWS may produce several broods each year. In the aggregate, however, the approximately 160 anadromous fish streams in WPWS (ADFG 1990) may have contributed to pre-spill production of harlequin ducks. Unfortunately, the lack of comprehensive baseline data and the unknown effects of habitat differences between EPWS and WPWS confound attempts to assess the effects of oil exposure on productivity.

Sources of Decline

The deaths of resident-breeding females and sublethal effects on reproduction of harlequins may have caused the low productivity observed in WPWS during 1989-1993. Piatt et al. (1990) discussed using a rate of 10 times the number of carcasses of sea ducks recovered to estimate actual casualties following the oil spill. Recovery of 210 corpses of harlequin ducks (about half of which were from WPWS) indicated that approximately 1,050 individuals (perhaps 300 females) died from initial exposure in WPWS. If half (or more) of these females were resident breeders in WPWS, it becomes apparent that direct mortality may have been an important factor in the observed low productivity in WPWS. Because of the inherent low recruitment rate of harlequin ducks in healthy populations (Goudie et al.1994), continued low productivity could be expected from harlequin ducks in the oil spill area.

The observed low SDI of molting harlequin ducks and broods in WPWS could have resulted from ingestion of petroleum. Ingestion of oil and resultant metabolic effects may have caused cessation of reproduction in other avian species (Grau et al. 1977; Butler et al. 1988; Fry et al. 1986; Eppley and Rubega 1990). Reduced reproduction in sea birds may result from stress or direct effects of oil on the adrenal system, leading to cascading effects with partial adrenal failure, inhibition of corticosterone feedback at the pituitary level, suppressed gonadotropin release, and inhibited reproduction (Rattner et al. 1984; Fry and Addiego 1988).

The massive human disturbance associated with oil spill clean-up activities in the years after the oil spill may have also contributed to the decline in harlequin breeding in WPWS (Cassirer and Groves 1992; Chadwick, 1992; Clarkson 1992; Wallen 1992; Patten et al. 2000).

Assessment of Northern Afognak Island

Streams of Afognak were similar in size and discharge to those of EPWS. Measurements of size and discharge of streams were most important in explaining variation between streams used by breeding harlequins and those that were not used in EPWS. The landscape on northern Afognak was less mountainous than EPWS, indicated by the significantly lower gradient and relief of basins of Afognak streams. Streams on northern Afognak generally flowed deep and fast, and stream substrate was boulder and cobble. Most streams in EPWS, by comparison, had a large component of gravel in the substrate. Woody debris was common on the upper banks of Afognak streams, as in EPWS. Each of the basins investigated on Afognak, with the exceptions of Otter and Phoenix Bay Creeks, had small areas of steeper gradient in upper elevations, typical of harlequin nesting habitat in Prince William Sound (Crowley 1993). The basins of lower gradient on Afognak contain a significantly greater number of lakes in their drainage networks than the steeper stream basins of EPWS (Table 13).

It is not known whether the presence of a lake within the drainage network of a stream affects the probability of use by breeding harlequin ducks. In EPWS, where lakes were relatively uncommon, there was no significant difference in the number of lakes between harlequin breeding streams and non-breeding streams (Crowley 1993). The lakes on Afognak are used by spawning red salmon. Roe from spawning pink and chum salmon provides a nutritious food supply for breeding harlequins in Prince William Sound (Dzinbal and Jarvis 1982; Crowley 1993). Harlequins have been observed on lakes in the Talkeetna Mountains, Alaska (Gabrielson and Lincoln 1959), Oregon (Couch, unpubl.), Canada (Salter et al. 1980) and Russia (Dement'ev and Gladkov 1967). Small flocks of harlequins were observed gathered at the outlets of lakes in Grand Tetons, Wyoming (Wallen 1987), Iceland (Bengtson 1972), Oregon (Couch, unpubl.) and

Canada (Clarkson 1992). Although nesting on lakes has not been directly observed in Alaska, brood-rearing by harlequins occurred on a lake in Prince William Sound (Dzinbal 1982), and various locations in Canada (Breault and Savard 1991; Clarkson 1992).

The large number of harlequins recorded near the mouths of some streams on Afognak during the first week of June suggested that breeding was occurring in those streams. Harlequins in EPWS gather at or near the mouths of breeding streams in spring, often flying upstream in small flocks. During the brief visit on 4 June to the mouth of Pauls Creek on Perenosa Bay, a mixed flock of 5 harlequins was seen flying up that stream, increasing the probability that harlequins breed in the Pauls-Laura Lake complex. This complex, which supports a substantial sockeye run, is a series of three lakes connected by stream channels.

Speculation on harlequin use of northern Afognak streams for nesting is complicated by the oiling history of Shuyak Straits and logging activity of the drainages south and east of Perenosa Bay. Breeding activity by harlequins can only be verified by monitoring streams for breeding females and broods. A large number of foxes observed on the shoreline surveys of the north end of Afognak suggests the possibility of higher rates of predation on nesting harlequins.

STATUS OF RESTORATION

Restoration of harlequin ducks is being pursued through strategies that protect habitats and reduce exposure to residual oil in the spill area. Habitat protection throughout Prince William Sound by land acquisition and land use regulation has the greatest potential to promote natural recovery of breeding birds and annual production. Production in EPWS is the most likely source of pioneers to the oil spill area. Careful management of timber harvest along vital nesting stream habitat is the primary challenge to maintain harlequin duck production in the east and ensure optimum habitat conditions for breeding birds in the spill region. Ongoing research in cleaning blue mussel beds in WPWS could aid in restoring harlequin ducks by removing sources of continued oil exposure that may be affecting reproductive success or survival.

Monitoring of harlequin duck populations should continue throughout Prince William Sound. Monitoring would provide more conclusive information on factors affecting annual breeding and production by harlequin ducks, as well as evidence of successful restoration in WPWS. Monitoring of both spring breeding birds and summer molt aggregations are important to assess the nature of declines suspected through 1993 (Patten et al. 2000) for various seasonal population segments. Continued monitoring would also provide insight into long term effects of oil exposure on a species that forages in intertidal zones and is sensitive to habitat disturbance.

CONCLUSIONS

Harlequin ducks suffered direct population losses, numbers of summer molting birds have declined, and productivity has been low in western Prince William Sound after the 1989 *Exxon Valdez* oil spill. In the three years of investigation, the average SDI of molting harlequin ducks was lower in WPWS compared to EPWS. We believe that the oil spill has likely reduced the number of harlequins molting in WPWS, but that differences in survey coverage and timing affected the accuracy of trend analysis.

The SDI of harlequin broods in EPWS was greater than in WPWS and the difference increased during the three years of study, indicating that harlequin productivity may be declining in WPWS. The SDI of harlequin broods during 1993 was 7.6 times greater in EPWS than in WPWS. The lack of baseline data prior to the oil spill and habitat differences between WPWS and EPWS, confound assessment of oil spill effects on productivity in WPWS.

We suggest that some combination of direct mortality of resident females and sublethal effects of oil on reproductive physiology and survival may have caused the low productivity and low numbers of molting of harlequin ducks observed in WPWS during 1991-1993. A relatively high proportion of molting harlequins inhabiting initially oiled habitats and habitats containing residual oil (e.g., mussel beds) indicate the potential for continued exposure to oil. Given the low productivity of harlequin ducks in healthy populations (Goudie 1990) and continued presence of oil in WPWS (Babcock et al. 1993), prospects of recovery for this species in PWS are uncertain and may not be evident for a long time. Monitoring of breeding birds, summer molting birds, and wintering aggregations should continue.

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Table 1. General location of shoreline surveyed for molting flocks and broods of harlequin ducks in the oil spill area of Prince William Sound, Alaska, 1991-1993.

Location	Year(s) Surveyed		
Aguliak		1992	1993
Applegate Island	1991	1992	1993
Bainbridge	1991	1992	1993
Block		1992	
Chenega	1991	1992	1993
Crafton Island	1991	1992	1993
Culross Island		1992	1993
Danger		1992	1993
Delenia		1992	1993
Disk Island		1992	1993
Eleanor Island		1992	1993
Eshamy Bay	1991	1992	1993
Elrington		1992	1993
Evans		1992	1993
Ewan Bay	1991		1993
Falls Bay		1992	
Flemming	1991	1992	1993
Granite Bay		1992	
Green Island	1991	1992	1993
Ingot Island	1991	1992	1993
Knight Island	1991	1992	1993
Latouche Island		1992	1993
Mainland	1991	1992	1993
Montague Island	1991	1992	
Mummy Island		1992	
Naked Island	1991	1992	1993
New Year's		1992	
Paddy Bay	1991		1993
Perry		1992	1993
Point Nowell		1992	1993
Port Nellie Juan	1991	1992	1993
Sphinx		1992	1993
Squire Island		1992	
Squirrel Island		1992	
Whale Bay	1991	1992	1993

Table 2. Survey of molting harlequin ducks in the oil spill area of western Prince William Sound, Alaska, 1993.

ISLAND Segment	Survey Date	No. Males	No. Females	No. Unident.	Total Flightless
APPLEGATE					
AE005B	7\30	14	2	0	14
BAINBRIDGE					
BA006B	8\9	18	5	0	18
CHENEGA					
CH009	8\9	2	2	0	2
CH010B	8\9	2	0	0	2
CH011A	8\9	10	0	0	10
Brizgaloff Creek	8\10	11	0	0	11
Totemoff Creek	8\10	3	4	0	3
CRAFTON					
CR002A	8\11	9	5	0	9
CR003A	8\11	3	0	0	3
CR004C	8\11	12	0	0	12
DELENIA					
DE001M	8\10	5	0	0	5
ESHAMY BAY					
EB009A	8\11	5	0	0	5
EB015A	8\11	6	0	0	6
EVANS					
EV010B	8\09	34	2	0	34
EWAN					
EW001A	8\26	1	0	2	3
EW001B	8\26	2	3	0	2
EW900	8\26	13	1	0	13
FLEMMING					
FL003A	8\09	23	5	0	23
GREEN					
GR004A	8\03	200	0	0	200
GR015A	8\03	43	5	0	43
GR300A	8\03	106	3	0	106
JACKPOT BAY	8\26	7	0	0	7
KNIGHT					
KN020A	7\05	20	15	0	20
KN021A	7\05	0	0	62	62
KN022	7\05	2	3	0	2

Table 2. (Continued)

ISLAND Segment	Survey Date	No. Males	No. Females	No. Unident.	Total Flightless
KNIGHT					
KN211D	7\05	15	0	0	15
KN300A	7\06	7	0	0	7
KN501A	8\02	0	2	0	0
KN505A	8\02	0	2	0	0
KN550	8\02	1	2	0	1
KN705A	8\05	2	1	0	2
LATOUCHE					
LA035	8\02	12	6	0	12
MAINLAND					
A002C	7\30	12	2	0	12
MA003A	7\30	10	0	0	10
MONTAGUE					
Hanning Creek	8\05	35	1	0	35
MUMMY					
MU001	8\05	11	4	0	11
PERRY					
PR008A	8\24	6	1	0	6
PR015	8\24	4	5	0	4
SQUIRE					
SQ005B	8\03	0	2	0	0
WHALE BAY					
WH003B	8\10	17	2	0	17
WH502	8\10	58	7	0	58
WH503	8\10	17	2	0	17
TOTALS:		758	94	64	822

Table 3. Comparison of boat surveys for molting flocks and broods of harlequin ducks in oiled and non-oiled areas of Prince William Sound, Alaska, 1991-1993.

	Oil Spill Area			Non-oiled Area [a]		
	1991	1992	1993	1991	1992	1993
Survey dates	7/06-8/23	7/16-8/06	7/05-8/26	7/23-8/09	7/28-8/20	8/09-8/18
Length (km)	537	2276	1296	700	410	620
Total ducks	693	2104	916	1448	760	1373
Shoreline density (n/km)	1.29	0.92	1.34	2.07	1.85	2.21
Average			1.18			2.04
SD [b]			0.23			0.18
Males (n)	350	473	758	491	359	644
Females (n)	6	412	94	181	129	385
% males (sex known)	--	53	89	73	74	63
Sex unknown	324	1208	64	724	255	344
Broods (n)	4	3	3	16	5	11
Broods/100 km	0.74	0.13	0.23	2.29	1.22 [c]	1.77
Average			0.37			1.76
SD			0.27			0.54

[a] From Crowley and Patten (1996).

[b] Standard deviation.

[c] Based on additional 120 km surveyed only for broods.

Table 4. Habitat use by harlequin ducks observed during the molt in the oil spill area of Prince William Sound, Alaska, 1993, including 441 ducks (58%) occupying initially-oiled shoreline and mussel beds containing residual oil.

Habitat Description	No. harlequins	% of total harlequins
Nearshore rocks	359	47
Stream mouths	108	14
Bays & lagoons	159	21
Total mussel beds	135	18
Total at residual-oil mussel beds [a]	112	14.7
Total	761	100
Oiled habitats	441	58

[a] Number of harlequins observed on mussel beds with residual oil (Babcock et al. 1993).

Table 5. Shoreline densities of harlequin ducks recorded on 38 occupied beach segments of varying oil impact in the oil spill area of Prince William Sound, Alaska, during the molt in 1993.

Oiling Conditions	No. Segments	No. Molting Harlequins	Km Shoreline	Density (birds/km)
Heavy	7	66	7.9	8.4
Moderate	7	52	6.3	8.3
Light	8	207	20.0	10.4
Very light	5	97	20.4	4.8
Non-oiled	11	339	69.6	4.9

Table 6. Harlequin duck broods observed during boat surveys of oil spill and non-oiled study areas of Prince William Sound, Alaska, 1993.

Location	ASC No. or Segment No.	Date	No. Young	Age Class	Habitat
Oil Spill Study Area					
Hanning Creek	227-10-17110	8/5	6	IIb	sandy estuary
Montague Is.	MN003-006				
West Twin Bay	none	8/24	2	IIc	protected bay
Perry Is.	PR015				
Jackpot/Ewan	none	8/26	6	IIc	rocky strait
Mainland	EW900				
Non-oiled Study Area [a]					
Control Creek	221-30-10520	8/10	2	IIc	estuary
Beartrap Bay	221-30-10490	8/11	1	IIc	estuary
Sheep River	221-20-10360	8/11	2	IIc	estuary
Raging Creek	221-20-10230	8/12	2	III	estuary
East Jack Creek	221-50-11230	8/16	3	IIb	estuary
Jack Bay	221-50-11231	8/16	4	IIb	estuary
Stellar Creek	221-50-11530	8/16	5	IIa	estuary
West Bligh Is.	none	8/17	1	IIb	nearshore rocks
Cloudman's Bay	221-40-11080	8/17	1	III	lagoon
Landlocked Bay	221-40-10990	8/17	2	III	nearshore rocks
Graveyard Point	none	8/17	1	III	rocky coast

[a] From Crowley and Patten (1996).

Table 7. Survey of harlequin duck broods in the oil spill area of western Prince William Sound, Alaska, 1993.

Location	Start Segment	End Segment	Date	Broods
Applegate Island	AE001A	AE007A	7/30	0
Bainbridge Island	BA001A	BA007A	8/09	0
Block Island	BL012A	BL012A	7/29	0
Chenega Island	CH017A	CH010B	8/09	0
Chenega Island	CH900A	CH010B	8/10	0
Crafton Island	CR001A	CR005D	8/11	0
Delenia Island	DE001M	DE001M	8/10	0
Disk Island	DI059A	IN031A	7/29	0
Eshamy Bay	EB005A	EB010A	8/11	0
Eshamy Bay	EB011A	PN005A	8/11	0
Eleanor Island	EL102B	EL104	8/26	0
Eleanor Island	EL104B	EL110B	7/29	0
Evans Island	EV010B	EV007A	8/09	0
Ewan Bay	EW001A	EW900	8/26	1 (6)[a]
Flemming Island	FL001A	FL005B	8/09	0
Granite Bay	GB001	GB002	8/11	0
Green Island	GR004A	GR004A	8/03	0
Green Island	GR001A	GR301B	8/03	0
Jackpot Bay	entire	entire	8/26	0
Knight Island	KN020	KN211D	7/05	0
Knight Island	KN300A	KN0111A	7/06	0
Knight Island	KN103A	KN104A	7/29	0
Knight Island	KN207A	KN405A	8/09	0
Knight Island	KN300A	KN553A	8/02	0
Knight Island	KN600A	KN601A	8/05	0
Latouche Island	LA035	LA043	8/02	0
Lone Island	LN012A	LN009	8/24	0
Mainland	MA003	MA001	7/30	0
Mummy Island	MU001A	MU900	8/05	0
Montague Island	Hanning B.	MacLeod B.	8/05	1 (6)
Naked Island	NA006	NA028A	7/29	0
Perry Island	PR015	PR004A	8/24	1 (1)
Squire Island	SQ001A	SQ005B	8/03	0
Whale Bay	WH500	WH505	8/10	0

[a] Number in parenthesis indicates number of ducklings.

Table 8. Summary descriptions of 12 streams investigated for potential value as breeding habitat for harlequin ducks on northern Afognak Island, Alaska, June, 1993.

Spatial Scale	Variable	Description
	Glacial origin:	0 streams
BASIN	Runoff origin:	12 streams
	Basin Slope:	2 - 30%, Mean 8.08%
	Basin Aspect:	4 NNE, 3 N, 2 NE, 3 NW
	Stream order:	1 - 3, Mode 2
DRAINAGE	Channel slope:	0.8 - 10.3 Mean 4.2%
NETWORK	Channel length:	0.3 - 38.6 km, Mean 11.83 km
	Lakes in network:	11 streams
	Channel pattern:	Slightly curved to curved, 1 meander
	Bank vegetation:	Tree shrub mosaic, debris/deadfalls
STREAM	Valley sideslope:	5 Enclosing, 4 Moderate, 3 Distant
MOUTH	Stream discharge:	0.5 - 3.0 m^3/sec, Mean 1.75
	Stream width:	3.0 - 15.0 m, Mean 7.6 m
	Primary veg.:	Old growth coastal Spruce-Hemlock
	Fish species:	Pink, silver and sockeye salmon
	Dominant hydrology:	Deep fast
	Dominant substrate:	Boulders and cobble

Table 9. Characteristics of 12 streams on northern Afognak Island investigated for potential use by breeding harlequin ducks in June 1993.

Stream Location	ASC [a]	Length km [b]	Slope % at Mouth	Basin Aspect	Width (m) at Mouth	Side Slope [c]
Bluefox Bay (SW)	251-50-10021	1.8	4	NNE	3	Encl
Bluefox Bay (SE)	251-50-10030	1.3	4	N	4	Encl
Redfox Bay (SW)	251-50-10045	1.1	3	NNE	4	Encl
Redfox Bay (S)	251-50-10050	10.3	5	NNE	12	Mod
Big Waterfall	251-82-10010	10.5	3	NE	15	Encl
Little Waterfall	251-82-10020	38.6	1	NE	8	Mod
West Delphin Bay	251-82-10026	17.2	2	N	7	Mod
Otter Creek	251-82-10045	4.7	1	N	5	Encl
Portage Creek	251-82-10050	37.7	1	NNE	15	Dist
Surprise Creek	251-82-10070	4.2	2	NW	8	Mod
Pauls Creek	251-82-10080	14.2	3	NW	5	Dist
Phoenix Bay	251-82-10086	0.3	1	NW	5	Dist

[a] Alaska Stream Catalog number (ADFG 1990).

[b] Includes lakes in drainage connected by this stream.

[c] Encl = enclosing, Mod = moderate, Dist = distant.

Table 10. Evaluation of streams on northern Afognak Island for potential use by breeding harlequin ducks in June 1993.

Stream Location	ASC [a]	Rating (1 - 5)[b]	Discharge (m^3/s)	Harlequins [c] in Estuary
Bluefox Bay (SW)	251-50-10021	1	1.0	--
Bluefox Bay (SE)	251-50-10030	1	1.0	55
Redfox Bay (SW)	251-50-10045	3	1.0	--
Redfox Bay (S)	251-50-10050	5	3.0	26
Big Waterfall	251-82-10010	2	2.5	--
Little Waterfall	251-82-10020	5	2.5	74
West Delphin Bay	251-82-10020	4	1.5	2
Otter Creek	251-82-10045	5	1.0	--
Portage Creek	251-82-10050	1	3.0	--
Surprise Creek	251-82-10070	4	1.0	6
Pauls Creek	251-82-10080	5	3.0	129
Phoenix Bay	251-82-10086	1	0.5	--

[a] Alaska Stream Catalog number (ADFG 1990).

[b] Rating from 1 = poor to 5 = excellent breeding potential.

Table 11. Comparison of characteristics from stream mouths of northern Afognak Island and eastern Prince William Sound, Alaska.

Variable	EPWS[a] (n = 48) Mean	S.D.	Afognak Is. (n = 12) Mean	S.D.	Unit	Transf.	Test	P -value
Area of Estuary	33.80	54.44	6.49	4.73	km^2	Log	Z = 2.45	0.014
Stream Width	13.07	8.22	7.58	4.23	m	Log	Z = 2.52	0.012
Volume Discharge	1.98	1.95	1.75	0.97	km^3/s	Log	Z = 0.47	0.637
Riparian Width	80.38	106.09	29.38	11.48	m	Log	Z = 1.29	0.201
Channel Slope	4.19	9.20	2.50	1.38	%	Log	Z = 0.37	0.710
Mean Sideslope	0.13	0.10	0.12	0.05	%	Log	Z = 0.17	0.868

[a] See Crowley (1993); Crowley and Pattern (1996).

Table 12. Comparison of characteristics from mouths of streams with moderate to high probability of use by breeding harlequins on Afognak Island and of known breeding streams in eastern Prince William Sound, Alaska.

Variable	EPWS [a] (n = 24) Mean	S.D.	Afognak Is. (n = 7) Mean	S.D.	Unit	Transf.	Test	P -value
Area of Estuary	50.29	63.76	6.36	4.19	km^2	Log	Z = 2.86	0.004
Stream Width	16.56	9.82	7.00	2.71	m	Log	Z = 2.88	0.004
Volume Discharge	3.18	2.11	1.86	0.94	km^3/s	Log	Z = 1.48	0.136
Riparian Width	116.10	135.70	30.83	12.81	m	Log	Z = 1.65	0.099
Channel Slope	2.85	1.81	2.43	1.40	%	Log	Z = 0.56	0.575
Mean Sideslope	13.00	8.00	13.00	5.00	%	Log	Z = 0.17	0.868

[a] See Crowley (1993); Crowley and Pattern (1996).

Table 13. Comparison of characteristics of basins and drainage networks of streams on northern Afognak Island and eastern Prince William Sound (EPWS), Alaska.

Variable	EPWS [a] (n = 48)		Afognak Is. (n = 12)		Unit	Test	P -value
	Mean	S.D.	Mean	S.D.			
Average basin slope	18.62	8.63	8.08	8.37	%	Z = 3.79	0.0002
Number of lakes	0.71	1.11	6.25	6.76	--	Z = 3.59	0.0003
Channel slope	9.83	6.25	4.21	3.63	%	Z = 3.41	0.0007
Basin relief	975	355	503	263	m	Z = 3.67	0.0002
Basin shape	0.66	0.16	0.55	0.20	--	Z = 1.90	0.0570
Basin area	15.30	16.10	18.26	18.60	km^2	Z = 0.38	0.7050
Basin perimeter	15.13	8.96	19.77	12.47	km	Z = 0.92	0.3550
Channels length	8.92	8.17	11.83	13.46	km	Z = 0.07	0.9480
Bifurcation ratio	3.45	1.70	3.46	1.29	--	Z = 0.37	0.7111
Channel frequency	3.85	3.52	4.17	4.04	--	Z = 0.18	0.8580
Stream density	0.70	0.29	0.61	0.25	km/km^2	Z = 0.96	0.3360

[a] See Crowley (1993); Crowley and Pattern (1996).

Table 14. Comparison of characteristics of basins and drainage networks of streams with moderate to high probability of use by breeding harlequin ducks on Afognak and of known breeding streams of eastern Prince William Sound (EPWS), Alaska.

Variable	EPWS [a] (n = 24)		Afognak Is. (n = 7)		Unit	Test	P -value
	Mean	S.D.	Mean	S.D.			
Average basin slope	15.51	5.34	5.14	3.18	%	Z = 3.69	0.0002
Number of lakes	0.67	1.05	7.14	7.00	--	Z = 2.91	0.0036
Channel slope	7.95	3.97	2.43	1.37	%	Z = 3.52	0.0004
Basin relief	1141	388	506	296	m	Z = 3.12	0.0018
Basin shape	0.65	0.16	0.49	0.20	--	Z = 2.10	0.0445
Basin area	23.52	19.01	18.68	15.52	km^2	Z = 0.73	0.4640
Basin perimeter	19.55	10.17	22.55	10.56	km	Z = 0.59	0.5550
Channels length	13.20	9.44	12.90	12.70	km	Z = 0.45	0.6530
Bifurcation ratio	4.01	1.73	3.94	1.39	--	Z = 0.04	0.9700
Channel frequency	5.38	4.16	4.57	4.47	--	Z = 0.81	0.4170
Stream density	0.67	0.26	0.60	0.26	km/km^2	Z = 0.57	0.5710

[a] See Crowley (1993); Crowley and Pattern (1996).

Table 15. Linear densities of molting harlequin ducks in occupied survey segments of the oil spill area of western Prince William Sound, Alaska, 1991-1993 surveys combined.

Oiling Conditions (birds/km)	No. Segments	No. Molting Harlequins	Km Shoreline	Density
Heavy	22	318	20.7	12.0
Moderate	20	384	36.5	11.3
Light	31	643	59.8	9.0
Very Light	42	741	149.1	3.8
Non-oiled	25	1,068	159.0	9.2
TOTALS:	140	3,154	425.1	

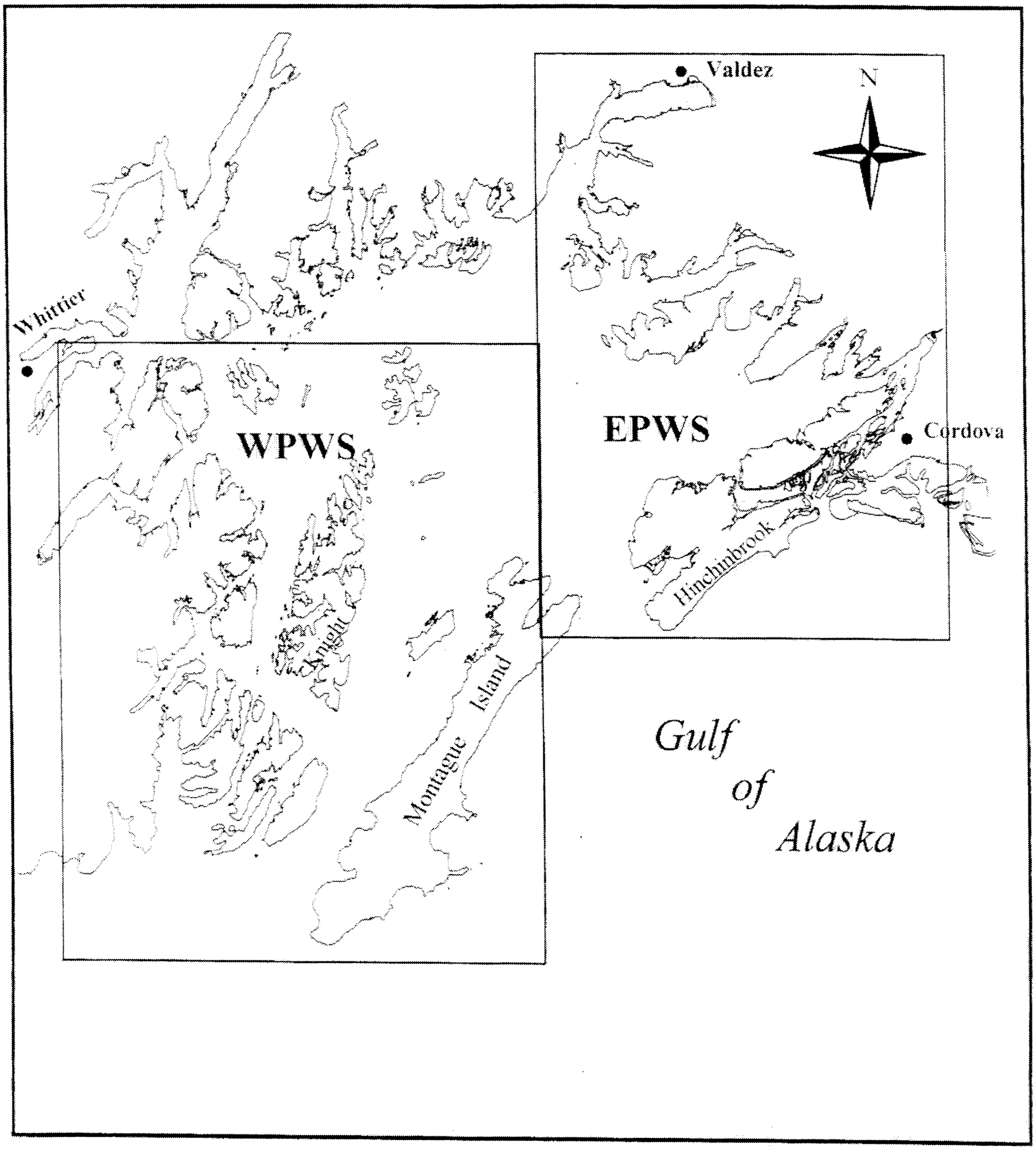


Figure 1. Study areas monitored for molting harlequin ducks in western (oil spill area) and eastern (non-oiled) Prince William Sound, Alaska during July-August 1991-1993.

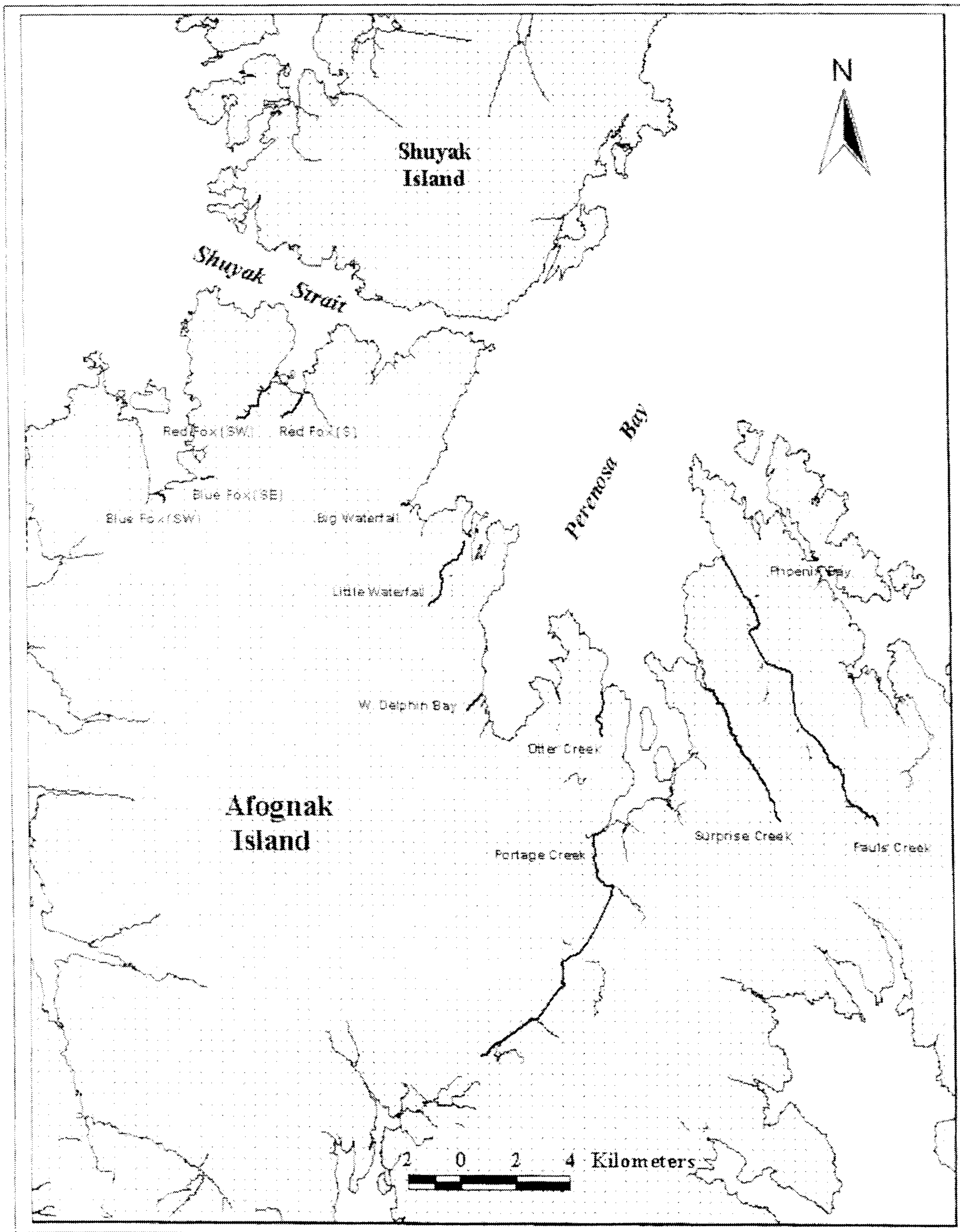


Figure 2. Study area on northern Afognak Island, Alaska where 12 streams were described and evaluated for suitability to breeding harlequin ducks in June 1993.

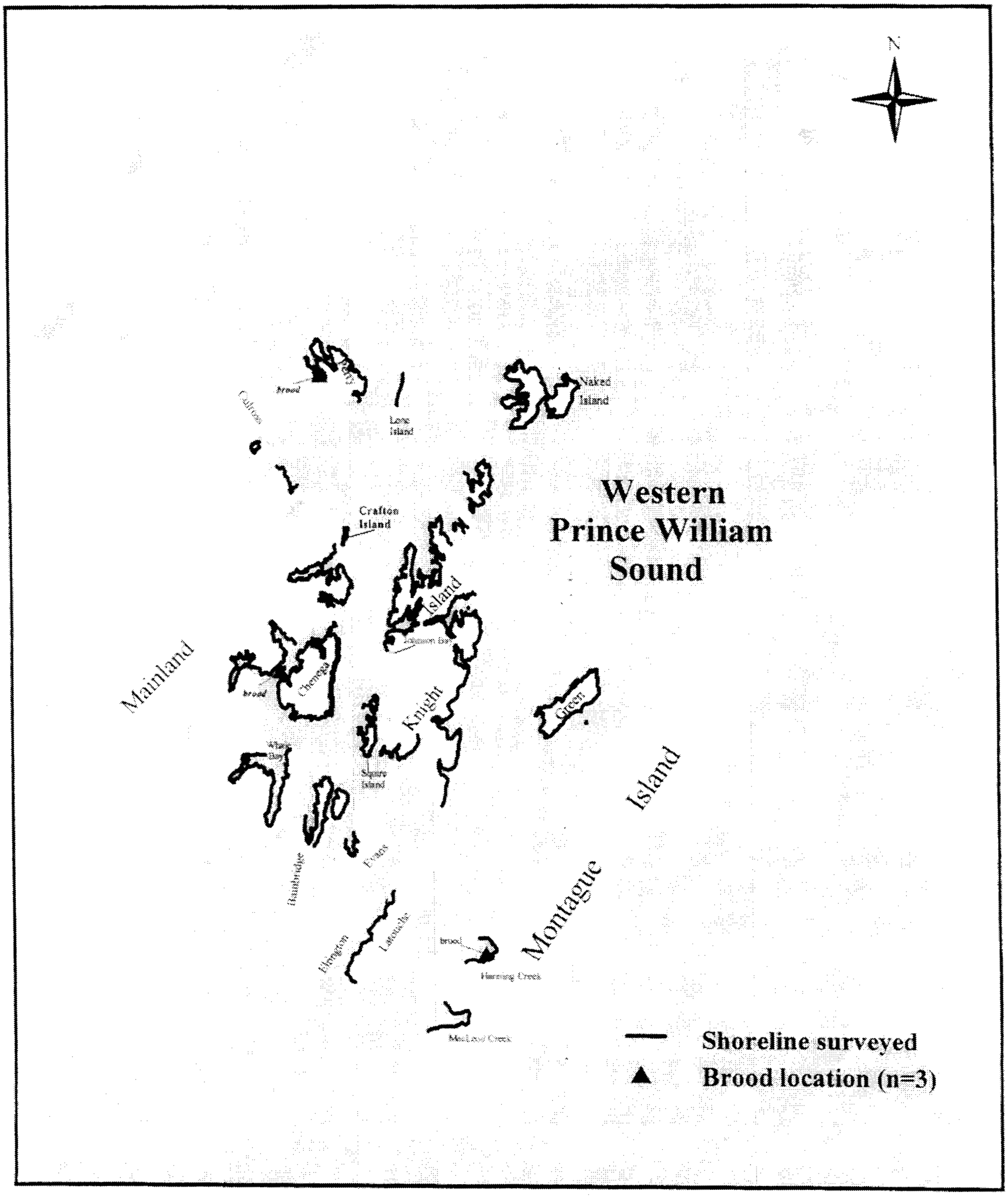


Figure 3. Shoreline surveyed for molting harlequin ducks and broods in the oil spill area of western Prince William Sound, Alaska during July-August, 1991-1993.

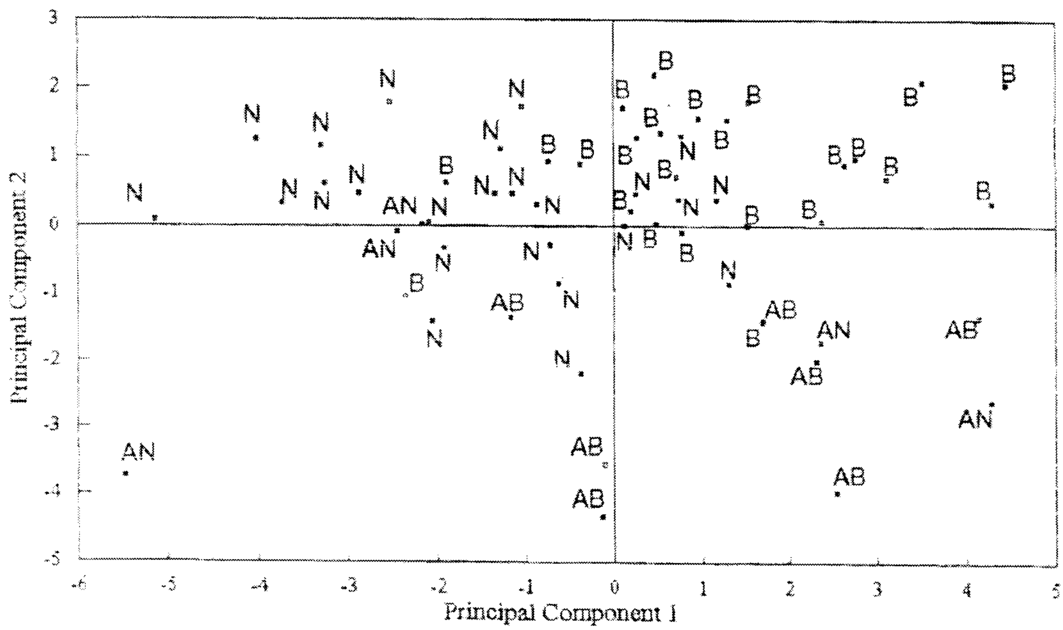


Figure 4. Principal component analysis of streams used (B) and not used (N) by breeding harlequin ducks in eastern Prince William Sound during 1991-1993, and streams rated in June 1993 with high (AB) and low (AN) probability of being used by harlequin ducks on northern Afognak Island, Alaska.

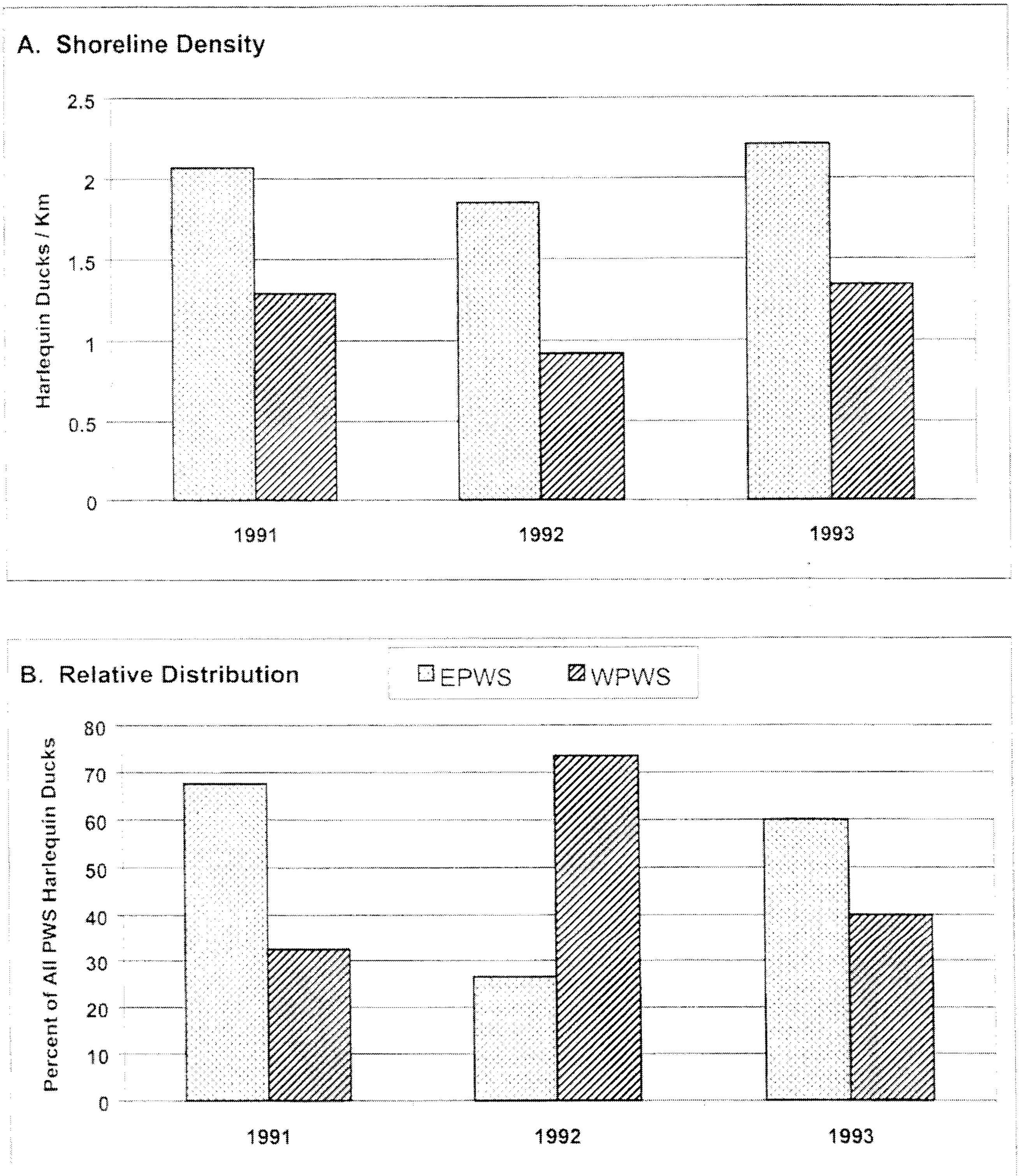


Figure 5. Shoreline density indices (A) and relative distribution (B) of harlequin ducks in non-oiled (EPWS) and oil spill (WPWS) areas of Prince William Sound, Alaska, during summers 1991-1993.

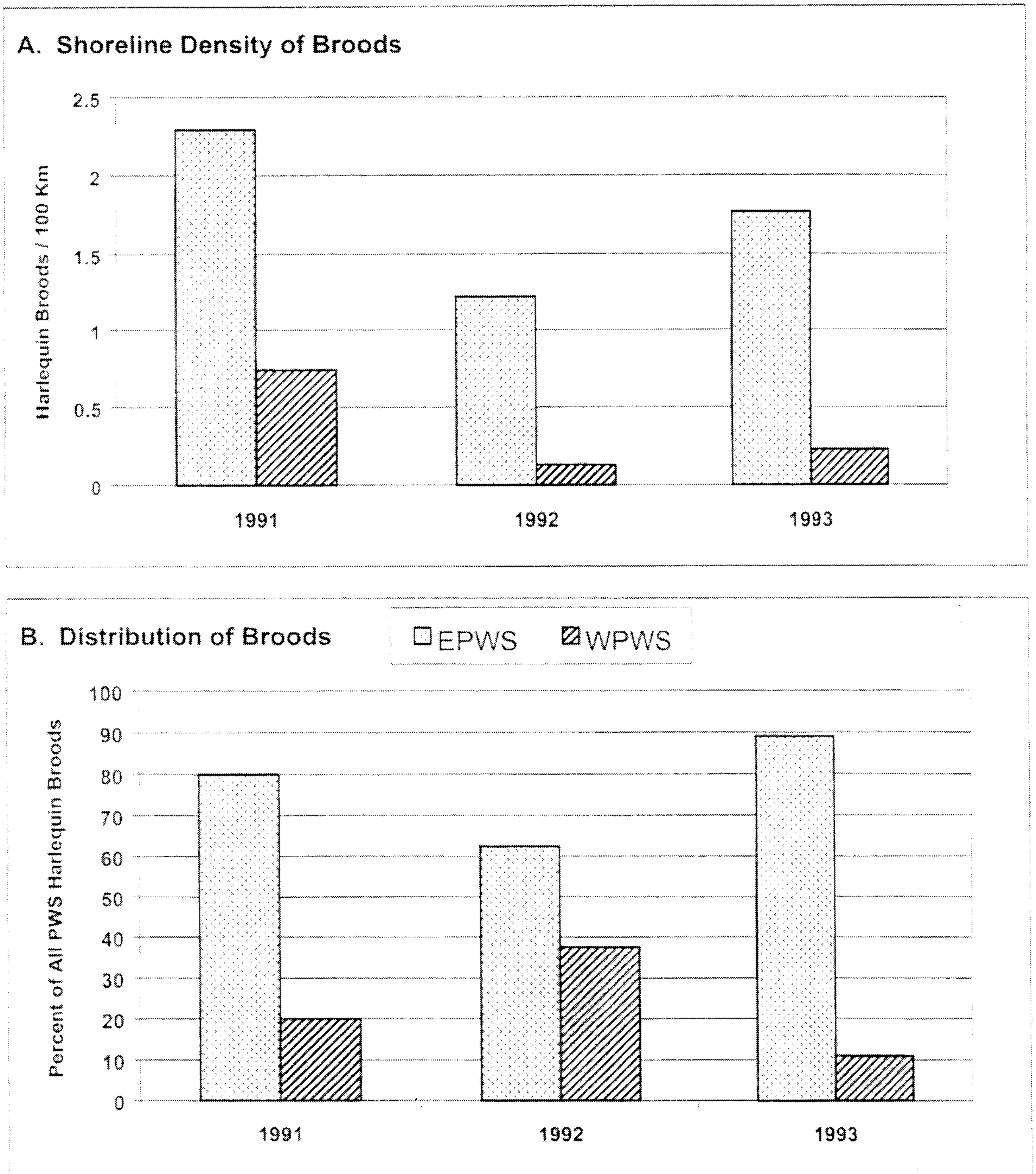


Figure 6. Shoreline density indices (A) and relative distribution (B) of harlequin duck broods in non-oiled (EPWS) and oil spill (WPWS) areas of Prince William Sound, Alaska, during summers 1991-1993.

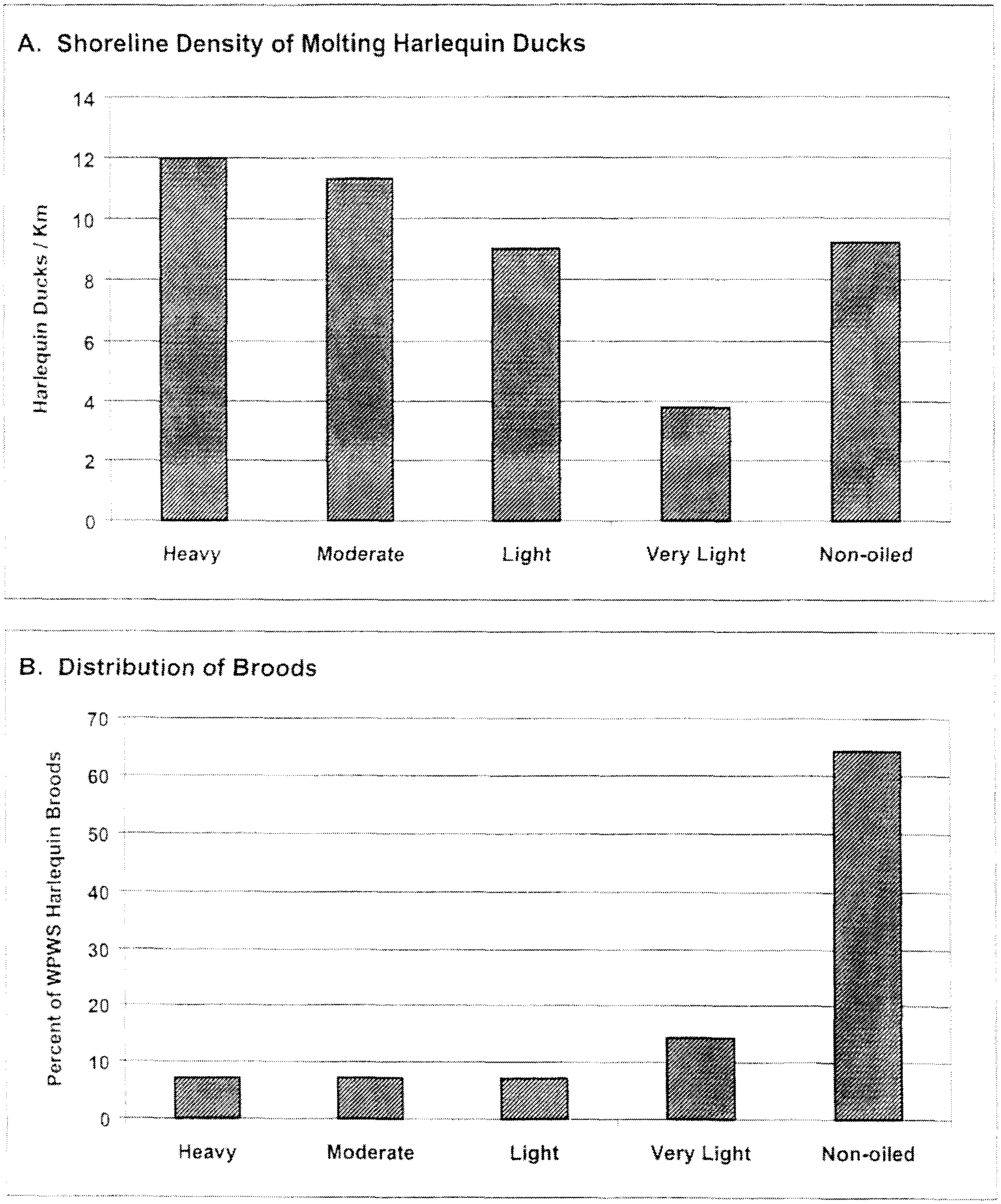


Figure 7. Shoreline densities of molting harlequin ducks (A) and distribution of broods (B) by shoreline oiling history in western Prince William Sound, 1991-1993 combined

APPENDIX 1. Standard operating procedures and data collection protocols for evaluation of harlequin duck breeding habitat on northern Afognak Island.

Harlequin Duck Habitat Documentation

Equipment List for Habitat Work:

Metal folder with the following:
- HARLEQUIN DUCK NESTING HABITAT: STREAM DATA FORM
- HARLEQUIN DUCK NESTING HABITAT: TERRESTRIAL DATA FORM
- Standard Operating Procedures
- Cross-section notebook – waterproof paper
- Pencils

Meter tape - 30 m
Meter stick (folding 2 m)
Clinometer
2 ping pong balls
Stop watch
Topographic maps
Spring scale - 100g
Calipers
Cardboard or rubber tube 1.5 in. diameter.
Flagging tape
Camera
Shotgun/ammo
Water/lunch
Survival Kit

1.0 The HARLEQUIN HABITAT DATA FORM (Table 1) must be used to describe habitat for all aspects of harlequin research <u>except</u> for nest site habitat.

1.1 These forms are used to describe trapping sites, molting sites, hen flock sites, brood rearing habitat, feeding sites and courtship or copulation sites.
1.2 Be specific in describing location.
1.3 Circle or fill in 1-3 features that best describe the habitat under each section.
1.4 Include comments, continue on back if necessary. Make a quick sketch of major features within 30 m of activity.
1.5 If a photo is taken, record film roll # and photo #.
1.6 Marine coastline types (under MARINE HABITAT) are:
- 1e: Boulder or bedrock islands, unvegetated, that remain exposed at high tide.
- 1s: Boulder or bedrock islands, unvegetated, that are submerged at high tide.
- 2: Uniform gravel or cobble beaches on mainland or vegetated islands.
- 3: Intertidal estuaries of permanent streams.
- 4: Rocky points off mainland or vegetated islands.
- 5: Vertical or sharply sloping cliffs.

2.0 Nest site habitat is recorded on 2 separate forms - the HARLEQUIN DUCK NESTING HABITAT: STREAM DATA FORM (Table 2) and the HARLEQUIN NESTING HABITAT: TERRESTRIAL DATA FORM (Table 3).

2.1 The first section of the STREAM DATA FORM documents location and hen I.D. Be very precise when describing location. Use GPS unit and record.

2.2 Using the 30-m tape, measure a 30-m plot along the stream channel, centered on the nest site.

2.2.1 While you and your partner are at opposite ends of the plot, use the clinometer to record gradient over plot length.

2.2.2 Measure width of the plot (stream channel width) at 2-3 spots.

2.2.3 Draw a map of the stream channel in the cross section notebook, using 2 notebook squares to the meter (4 notebook squares = 1 m^2.

2.2.4 Use the 2-m stick to measure (to the nearest meter) the STREAM CHARACTERISTICS listed on the data form, and draw them to scale on the map of the stream plot.

2.2.5 Use a ping-pong ball and a stop watch to determine velocity.

2.3 The next section, Stream Variables, is a more general accounting of stream habitat. Complete all sections at nest site, using topographic maps when necessary.

3.0 Fill out all information in the TERRESTRIAL DATA FORM at the nest site.

3.1 The form is divided into NEST SITE HABITAT, which measures specific parameters of the site, and AREA HABITAT, a general description of the area and watershed. Since we will not be locating nests on Afognak during 1993, use the AREA HABITAT section.

3.2 UNDERSTORY (vegetation < 1 m tall) AND OVERSTORY (vegetation > 1 m tall) is determined to species for the 3 most prominent species within 10 m of the nest bowl.

3.2.1 Estimate percent cover of UNDERSTORY over the area for each species as though the sight is being viewed from above.

3.2.2 Repeat exercise for OVERSTORY vegetation and for CRYPTIC NEST COVER within 1 m of the nest bowl.

3.2.3 Measure the closest distance from the nest to a stream, to old growth forest if the nest is in riparian vegetation, and to harvested timber, if applicable.

3.2.4 Describe the type of nest bowl material and cover.

3.3 Complete the AREA HABITAT section, using topographic maps when necessary.

3.4 Photograph stream channel and vegetation from several perspectives.

3.5 Write additional comments on back of data forms.

Table 1. Habitat data (ground truth) collected at harlequin duck activity sites on Afognak Island, Alaska in 1993.

HARLEQUIN DUCK HABITAT DATA FORM [a]

Harlequin Restoration Project, Afognak Island, Alaska

DATE: BROOD SIZE:
TIME: HEN I.D.#:
LOCATION: FREQ:
Mark location on map PHOTO #:

IMMEDIATE AREA OF ACTIVITY

ACTIVITY HABITAT		SUBSTRATE		STREAM HABITAT		MARINE	
SW	Swimming	BE	Bedrock	SS	Shallow slow	ES	Estuary
RO	Roosting	BO	Boulder (>30cm)	SF	Shallow fast	BA	Protected Bay
DI	Diving	CO	Cobble (8-30cm)	DS	Deep slow	OS	Open sound
PR	Preening	GR	Gravel (.2-8cm)	DF	Deep fast	GU	Gulf
CT	Courtship	SA	Sand	BR	Boulder run	Type:	1e 1s 2
FD	Fled dive	SI	Silt	PW	Pocketwater		3 4 5
FF	Flushed	VE	Vegetation	BW	Backwater	Water depth:	
				FA	Falls		

BANK OR BEACH COMPOSITION		FOREST AGE CLASS		HARVEST STATUS	
TR	Trees	OG	Old-growth	UN	Unharvested
SH	Shrub	MA	Mature	RH	Recect (< 10 yr)
TS	Tree/shrub mosaic	IM	Immature	OH	Old harvest (>10 yr)
GF	Grass/forbs	PO	Pole	SG	Second growth
BE	Bedrock	SA	Sapling	BU	Buffer, width:
SA	Sand	SE	Seedling	CL	Clearcut
GR	Gravel,cobble,boulder				
DE	Debris/deadfalls				
RO	Roots	Width of riparian zone:___m			

TOPOGRAPHY
Altitude:___
Slope:_____
Aspect:_____
Sideslopes: Enclosing
Moderate
Distant

TURBIDITY
CL Clear
ST Slightly turbid
TU Turbid
Color, if any:___

HYDROLOGY
Stream length:____km
Dist. to estuary:
Width at activity:__m
Width at mouth:____m

CHANNEL TYPE
ST Straight
SC Slight curve <45°
CU Curved 45 - 90°
BR Braided
Describe islands if present
(veg, size)

SPAWNING STATUS
Salmon present: Y N
Species:_______
Spawning: Y N

HARLEQUIN FLOCK
Males:
Adult ___ Juv ___
Females:
Breed ___ Nonbreed ___
Total:
Mated pairs: ____
Broods: ____

COMMENTS:

[a] Compiled, in part, from Cassirer and Groves (1991).

Table 2. Aquatic data (ground truth) collected at potential harlequin duck nesting streams on Afognak Island, Alaska in 1993.

HARLEQUIN DUCK NESTING HABITAT: STREAM DATA FORM

Harlequin Restoration Project, Afognak Island, Alaska

DATE:	BROOD SIZE:
TIME:	HEN I.D.#:
LOCATION:	FREQ:
Mark location on map	PHOTO #:

MAP TO SCALE 30 m STREAM PLOT [a]: 1 at nest site, 2 random w/in 0.5 km

STREAM CHARACTERISTICS		DESCRIPTIONS
TA	Total Area	Measure of stream size since length is constant
SS	Shallow Fast	Area of water <.5m deep, velocity <.3m/s.
SF	Shallow Fast	Area of water <.5m deep, velocity >.3m/s.
DS	Deep Fast	Area of water >.5m deep, velocity <.3m/s.
DF	Deep Fast	Area of water >.5m deep, velocity >.3m/s.
BR	Boulder Run	Area of DF water with boulder induced turbulence.
FD	Forest Debris	Area of logs, branches in and over streams.
RV	Riparian Veg	Area of over-hanging vegetation.
UN	Undercut Bank	Area of undercut stream bank.
PW	Pocketwater	Area of SF or DF water creating small pools.
BW	Backwater	Area of slack water off main stream channel.
FA	Falls	Area of waterfalls > 1m high, include plungepools.
LO	Loafing Sites	Number emergent, slightly submergent boulders.

STREAM VARIABLES [b]

SUBSTRATE

BE	Bedrock
BO	Boulder (>30cm)
CO	Cobble (8-30cm)
GR	Gravel (.2-8cm)
SA	Sand
SI	Silt

CHANNEL TYPE

ME	Meander
BR	Braided
ST	Straight
CU	Curved

TURBIDITY

CL	Clear
ST	Slight turbid
TU	Turbid

ORGANISMS

Salmon present: Y N
Species:
Spawning: Y N

HYDROLOGY

Stream length:
Dist. to estuary:
Width at nest site:
Discharge at mouth:

TOPOGRAPHY

Gradient:
Altitude at origin:
Aspect:
Stream order:

COMMENTS:

[a] Compiled, in part, from Oswood and Barber (1982).
[b] Compiled, in part, from Cassirer and Groves (1991).

Table 3. Terrestrial data to be collected in potential harlequin duck nesting habitat on Afognak Island, Alaska in 1993

HARLEQUIN DUCK NESTING HABITAT: TERRESTRIAL DATA FORM [a]

Harlequin Restoration Project, Afognak Island, Alaska

DATE: BROOD SIZE:
TIME: HEN I.D.#:
LOCATION: FREQ:
Mark location on map

NEST SITE HABITAT: Complete for 10 m plot.

NEST SUBSTRATE MATERIAL		LANDFORM		NEST BOWL	
BE	Bedrock	MN	Mainland	GS	Grasses
BO	Boulder (>30cm)	IS	Island	DO	Down
CO	Cobble (8-30cm)	PE	Peninsula	VE	Vegetation
GR	Gravel (.2-8cm)	SB	Streambank		
SA	Sand		UN Undercut		
SI	Silt		VE Vertical		
LI	Litter/vegetation		SL Sloping		
		FL	Floodplain		

UNDERSTORY (ht<1m)	OVERSTORY (ht>1m)	CRYPTIC NEST COVER	
Sp1:_____%__	Sp1:_____%__	RO	Rock crevice
Sp2:_____%__	Sp2:_____%__	TR	Tree cavity
Sp3:_____%__	Sp3:_____%__	DF	Deadfall
Veg Density: HEV MOD SPARSE	HEV MOD SPARSE	VE	Vegetation
			% Species:

Measure Distance To: STREAM:____

FOREST: ____ HARVEST: ____

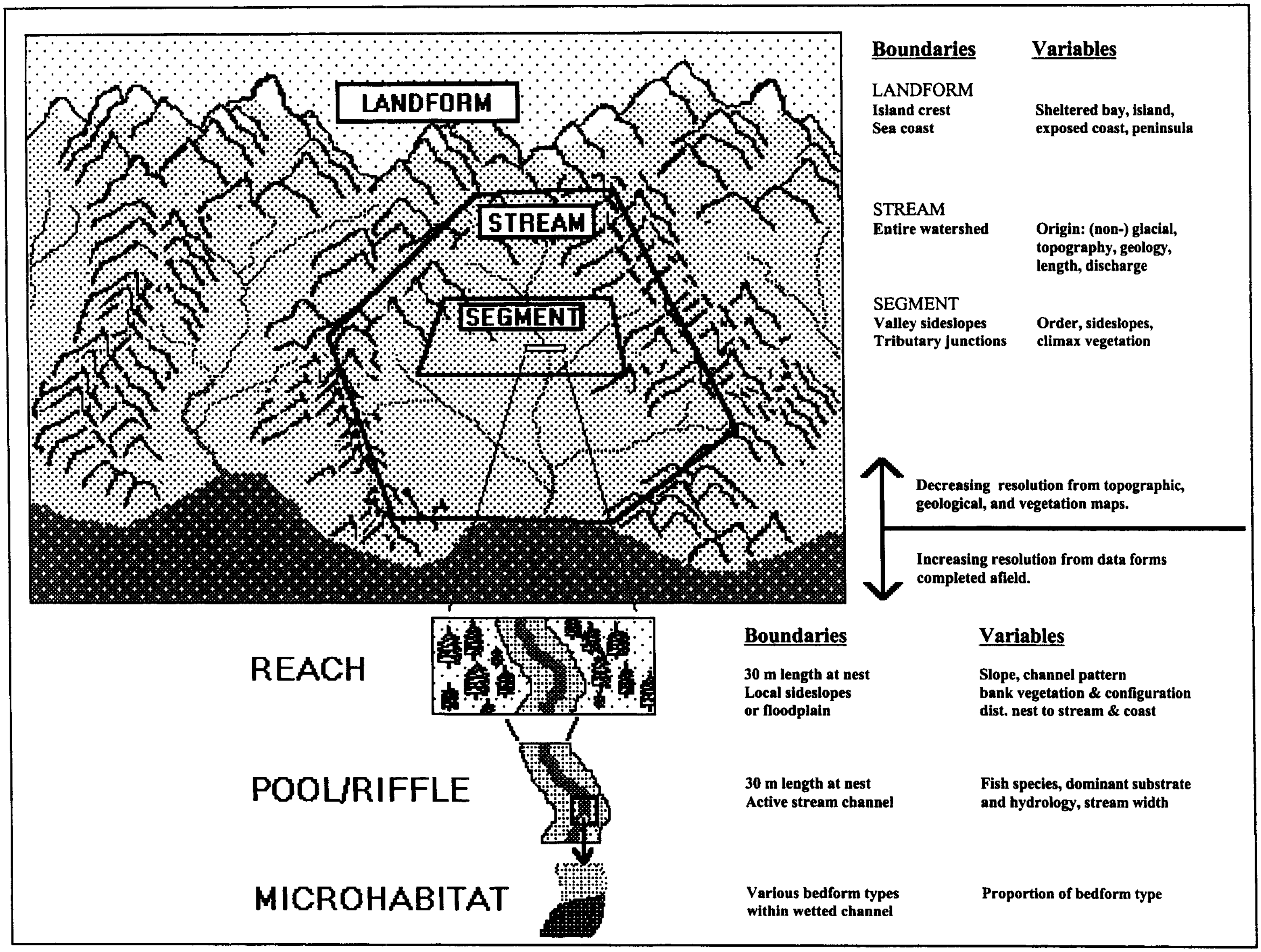
AREA HABITAT

SPRUCE-HEMLOCK FOREST (specify if not S-H)		HARVEST STATUS		BANK COMPOSITION (list species and % on back)	
OG	Old growth	UN	Unharvested	TR	Trees
MA	Mature	RH	Recent (<10 yr)	SH	Shrubs
IM	Immature	OH	Old harvest (>10yr)	TS	Tree/shrub mosaic
PO	Pole	SG	Second growth	GF	Grass/forb
SA	Sapling	BU	Buffer width:	DE	Debris
SE	Seedling	CL	Clear-cut no buffer	SA	Sand
				SI	Silt
				GR	Gravel/cobble/boulder
				BE	Bedrock
				RO	Roots

TOPOGRAPHY: Altitude:___ Slope:___ Aspect:___

[a] Compiled, in part, from Cassirer and Groves (1991).

Figure 1. Diagram of hierarchical system levels for description and classification of stream habitat on Afognak Island[a].



[a] Adapted from Crowley (1991) and Crowley and Patten (1996)

APPENDIX 2. Characteristics of Potential Harlequin Duck Breeding Streams Investigated on Northern Afognak Island, June 1993.

Bluefox Bay Stream (SW). ASC 251-50-10021. This stream is located in Bluefox Bay, northern Afognak Island, and was surveyed on June 3, 1993. The permanent stream ends in an intertidal estuary in a protected bay. This stream received a poor rating (1 on 1-5 scale) as potential harlequin breeding habitat. The stream substrate is boulder and cobble which forms a shallow fast boulder run. Bank composition is a tree/shrub mosaic with debris and deadfalls. The forest type at the mouth of the stream is old-growth and unharvested. The width of riparian zone is 20 m and the slope is 4 percent. The stream aspect is NNE. The width of the stream at the mouth is 3 m at a depth of 20 cm in early June. The stream drains from a small lake at an elevation of approximately 180 m. The volume of flow is approximately 2-3 cfs. The stream is steep, curved and shallow, and appears to be marginal harlequin breeding habitat. The overstory is an enclosed old growth canopy, perhaps navigable by flying harlequins. Pink and silver salmon spawn in the lower reaches of this stream. Harlequin ducks were not observed in the estuary or along this stream.

Bluefox Bay Stream (SE). ASC 251-50-10030. This stream is located in Bluefox Bay, northern Afognak Island, and was surveyed on June 3, 1993. The stream was rated poor (1) as potential harlequin breeding habitat. The stream ends in an intertidal estuary in a protected bay. The substrate of the stream is gravel. The stream is shallow, with a water depth of 15 cm and width of 2 m about 150 m from the estuary. The stream drains from two small lakes located at 30-60 m elevation. The stream width at the mouth is 4 m. The bank composition is a tree/shrub mosaic, with debris/deadfalls, with gravel, cobble, and boulders forming the sides of the bank. The forest age class at the mouth of the stream is old-growth, unharvested. The slope of the stream is 4%, and the stream aspect is NW at sea level; the sideslopes are enclosing. The stream channel is slightly curved and braided near the mouth. This is a pink salmon spawning stream with a definite enclosed overstory, perhaps navigable by flying harlequins. The volume of flow of the stream is 3-5 cfs at the mouth. There are many offshore rocks, islets and stacks with extensive intertidal areas in Bluefox Bay. Approximately 55 Harlequins were counted in Bluefox Bay.

Redfox Bay Creek (SW end). ASC 251-50-10045. This stream is located in Redfox Bay, northern Afognak Island and was surveyed on June 3, 1993. It was rated moderate (3) for suitability as harlequin breeding habitat. The permanent stream ends in a small intertidal estuary in a protected bay with offshore rocks. The stream drains from two small lakes located at less than 35 m elevation. The substrate of the stream is boulder, cobble, and gravel. The stream habitat is shallow-slow to shallow-fast. The bank composition is a tree/shrub mosaic. The forest age class is old-growth, unharvested. The width of the riparian zone is 20 m. The slope at the site of investigation, 50 m from the estuary at elevation 1 m, is 3 percent. The aspect of the stream mouth is NNE. The sideslopes of the stream are enclosing. The width at mouth is 4 m and the width of streambed is 8 m. Channel type is slightly curved. This is a pink and silver salmon spawning stream. The stream overstory is not completely enclosed by trees, but is semi-enclosed, perhaps navigable by flying harlequins. Bank debris does not completely block the stream; only one log blocks the stream flow at the site of investigation. The stream depth was 12 cm and flow was 4 cfs at the mouth during the site visit.

Redfox Bay (S) Stream. ASC 251-50-10050. This stream is located in Redfox Bay in northern Afognak Island. Redfox Bay opens north directly to Shuyak Straits. Approximately 26 harlequins were counted on offshore rocks in Shuyak Straits near Redfox Bay on June 3, 1993. The stream received an excellent rating (5) as harlequin breeding habitat. The estuary is located in a protected bay. The stream drains from five small lakes, the highest of which is at approximately 150 m elevation. The stream habitat is deep-fast which forms a boulder run, but not a cascade. The stream bank composition is a tree/shrub mosaic above gravel, cobble, and boulders, indicating high flows at certain times of the year. The forest age class at the stream mouth is old-growth and unharvested. The width of the riparian zone is 20 m. Altitude at the inspection site is 2 m; slope gradient at the mouth is 5 percent; the stream aspect at the mouth is north. The stream sideslopes are moderate. The stream is clear and the streambed is 15 m wide; the channel type was curved to slightly curved. The stream was 12 m wide and 50 cm deep in June, 50 m from estuary. The stream is believed to be a harlequin breeding site. Pink and red salmon, as well as Dolly Varden trout, spawn in this drainage. The overstory is open and navigable by harlequins.

Big Waterfall Creek. ASC 251-82-10010. Big Waterfall Creek is located on the west side of Perenosa Bay on northern Afognak Island. The creek was surveyed on June 4, 1993. Harlequin ducks were not observed in the estuary. This permanent stream ends in an extensive intertidal estuary in protected Big Waterfall Bay, which has many offshore rocks. The stream substrate is composed of boulders, cobble, and gravel. Big Waterfall originates at approximately 250 m elevation and is fed by three lakes. The stream habitat is deep-fast and the stream is clear. The stream channel type is curved. The bank composition is a tree/shrub mosaic, with exposed gravel, cobble, and boulders below the shore, indicating higher flows at certain times of year, such as during spring breakup. Forest age class is old-growth, unharvested. The width of riparian zone is 30 m, with an open overstory. The stream sideslopes are enclosing. Flow rates of Big Waterfall are estimated at approximately 7-10 cfs. The stream overstory is completely open. This appears to be an ideal harlequin breeding stream except for the large vertical falls (20 m) near the stream mouth. The falls are visible from the coastline. The valuation of Big Waterfall as a potential Harlequin breeding stream is therefore 2 on scale of 5. In contrast, harlequins probably breed in adjacent Little Waterfall Creek. The altitude at the mouth of Big Waterfall Creek is 2 m and the slope is 3 degrees. The aspect of the stream mouth is NE. The distance to estuary at site of the investigation was 50 m. The stream width at the mouth was 15 m. The depth of the stream near the mouth in early June was 40 cm. It is possible that some harlequins may breed along the lower reaches of Big Waterfall Creek, before the falls. Pink salmon spawning and silver salmon rearing are known to occur in the short reaches below the falls; salmon do not pass these falls.

Little Waterfall Creek. ASC 251-82-10020. Little Waterfall Creek is located in Middle Waterfall Bay, on the west side of Perenosa Bay on northern Afognak Island. Little Waterfall was surveyed on June 4, 1993 and was rated as a 5 (excellent) on the harlequin habitat scale. This valuation is qualified by the occurrence of two large waterfalls, which are, however, surmounted by weirs and fish ladders. Approximately 74 harlequins, including at least five pairs, were counted on offshore rocks in NW Perenosa Bay off the mouth of Little Waterfall Creek. This stream originates at approximately 160 m elevation and is fed by two lakes, one larger and one smaller. The stream width is approximately 6.5 m at the mouth. The stream appears ideal except for the two large falls. There are also three other steep passes of 1.2 m, 1.8 m, and 2.2 m which would not stop egress of harlequin ducklings. The first large falls (9 m) is located approximately 1 km from the mouth; the second large (12 m) waterfall is vertical and located near the lake. The first falls has been by-passed by a fish ladder/weir. Little Waterfall Creek ends in a protected bay which has an extensive intertidal and offshore rocks. Juvenile sockeye have been stocked in one of the lakes drained by the stream. An extensive eelgrass intertidal is found in the small bay directly in front of the stream mouth. Little Waterfall Creek has a cobble/gravel substrate and a deep-fast flow. The estuary is located in a protected bay with large intertidal zone. The stream bank composition is a tree/shrub mosaic. The surrounding forest is unharvested old-growth. The riparian zone is approximately 50 m, and the stream was 70 cm deep in early June near the estuary. At the stream mouth, the elevation is 1 m, the slope is 1 degree, and the aspect at the mouth is NE. The sideslopes of the stream are moderate. The stream is clear. The estuary and bay adjoining the mouth appear to be in an earthquake uplifted zone. The overstory above the creek is completely open. The estuary extends approximately 1.8 km in a protected bay with steep cliffs, and has a large tidal influence. The channel type of Little Waterfall Creek is slightly curved. Pink and silver salmon, and Dolly Varden spawn in this stream. Floy "spaghetti" tags found in the stream were from sockeye salmon.

West Delphin Bay Creek. ASC 251-82-10026. West Delphin Bay Creek is located west of Delphin Island in Delphin Bay on northern Afognak Island. The stream was surveyed on June 4, 1993. This is the northernmost of two streams on the west side of Delphin Island. One pair of harlequins was recorded at the tip of a peninsula on the east side of Delphin Bay near Delphin Island. The valuation of the West Delphin Bay Creek as potential Harlequin breeding habitat was good (4). The boulder or bedrock islands in the immediate estuary are protected, but north-facing Delphin Bay remains exposed at high tide. The lower falls of the stream, shortly before the estuary, form a 3-m cascade at low tide, which is clearly passable by fish at high tide. The stream substrate is bedrock, boulder, and cobbles. The stream habitat is deep-fast. The stream bank composition is a tree/shrub mosaic above sides of gravel, cobble, and boulders, which indicate higher flow rates during spring break-up. The forest age-class surrounding the creek is old-growth and unharvested. The width of riparian zone is 40 m. The stream originates at approximately 160 m elevation and is fed by a series of five small lakes. The altitude at the stream mouth is 3 m, the slope is 2 degrees, the aspect of the stream mouth is northeast, and the sideslopes are moderate. West Delphin Bay Creek is clear, 7 m wide at the mouth, and has a flow rate of 4-6 cfs. The stream depth at the mouth is 35 cm. The channel type is slightly curved. Pink and silver salmon, and Dolly Varden trout spawn in the estuary and lower reaches of the stream. The overstory above the stream is open and considered navigable by flying harlequins.

Otter Creek. ASC 251-82-10045. Otter Creek is located on the northwest side of Discoverer Bay which is found at south end of Perenosa Bay in northern Afognak Island. It was rated excellent (5) as harlequin duck habitat, although harlequins were not recorded near this stream. Otter Creek has a well-developed intertidal estuary with abundant blue mussels. Otter Creek originates at Otter Lake at approximately 25 m elevation. This permanent stream ends in a protected bay with long tidal flats. The stream substrate of Otter Creek is boulder, cobble, and gravel. The stream habitat in June is shallow-slow, with a pool-riffle complex. The bank composition is a tree/shrub mosaic with debris/deadfalls. The bank has large, woody debris above sides of boulder, cobble, gravel, indicating higher volumes of flow and fluctuating water levels. The stream flow is buffered by drainage from Otter Lake. Average snow depth in April in the vicinity is usually approximately 1 m. The forest age class is large old-growth (20-m trunks) and unharvested. The width of riparian zone is 20 m, which is a relatively narrow. At the site of investigation stream width was 5 m and depth was 40 cm. The mouth of creek has a NNE aspect. The sideslopes of Otter Creek are enclosing, with a high steep bank. The channel type is slightly curved. There is a cataract near Otter Lake, but fish can pass this barrier and there are no other barriers to fish movement. Tidal influence extends approximately 500 m inland from mouth of Otter Creek; however tidal back up may raise the stream level to Otter Lake. The stream corridor is open with occasional drift logs embedded in the bank. The overstory is enclosed, but certainly passable for flying harlequins. Low flow of Otter Creek is 2 cfs in June; high flood levels during breakup may rise to 40 cfs. Fish use of Otter Creek is high and includes spawning Dolly Varden and rainbow trout, steelhead, and pink, silver, and sockeye salmon. The spawning fish attract brown bears to Otter Creek. Otter Creek Road, a 1230 Forest Service logging road, crosses this stream. This road, in construction in 1993, is separate from the main Afognak road system. At the road crossing, the lower bank of Otter Creek is 7 m and the stream width was 5 m. River otter, deer, and elk frequently occur in the Otter Creek drainage. Upper Otter Lake has a cobble and boulder bottom with portions of a flat gray rock substrate. An extensive pool-riffle complex forms the outlet of the lake to the stream.

Portage Creek. ASC 251-82-10050. Portage Creek is located at the south end of Discoverer Bay in Perenosa Bay on northern Afognak Island. The Portage Creek area was not considered for EVOS Trustee Council acquisition in 1993 because the drainage has been logged. No harlequins were observed in Discoverer Bay at the time of the survey on June 4, 1993 and the creek was rated poor (1) as harlequin habitat. Portage Creek originates in Portage Lake at 18 m elevation. Portage Creek has a large shallow estuary with eelgrass, and a large archeological site. Portage Lake has spawning sockeye, whereas Portage Creek has spawning silver and pink salmon, as well as Dolly Varden. There is an approximately 1/2-mile forested perimeter around Portage Lake. The area beyond this perimeter has been logged and was treeless in 1993. A log transfer site was located at Discoverer Bay to the north of the mouth of Portage Creek. This log transfer site operated from the early 1980s until 1990. A road extended from this log transfer site to the extensive logged areas farther to the southeast on Afognak Island.

Surprise Creek. ASC 251-82-10070. Surprise Creek is located between Pauls Bay and Discovery Bay on the east side of Perenosa Bay, northern Afognak Island. The site was surveyed on June 4, 1993. This permanent stream ends in a small and narrow bay which forms an elongated (3 km) intertidal estuary in which harlequins were present. Two pairs were observed at the mouth of this small bay; 1 other adult female and 1 juvenile were also recorded. This stream was rated as good (4) on the 1-5 scale as potential Harlequin breeding habitat. Surprise Creek has a boulder and cobble substrate. The stream habitat is shallow-fast; the marine habitat is that of an estuary in a protected bay. The bank composition is a tree/shrub mosaic and the forest age class is old-growth and unharvested. The overstory above the stream is open. The width of the riparian zone is 35 m. The slope of the stream is 2 degrees and the aspect to the stream mouth is northwest. The sideslopes of Surprise Creek are enclosing to moderate. There is no turbidity to the stream and the water is clear. The stream width at mouth was 8 m, with a depth of 25 cm. The channel type is slightly curved. Surprise Creek hosts spawning pink salmon and silver salmon fingerlings.

Pauls Creek - Laura Lake Complex. ASC 251-82-10080. This productive drainage is located on the east side of Perenosa Bay on northern Afognak Island. The site was surveyed on June 4, 1993. This chain of lakes, joined by a stream, received a valuation of excellent (5) potential habitat for harlequin ducks. In the estuary, known as Pauls Bay, many unvegetated boulder or bedrock islands remain exposed at high tide. Approximately 79 swimming and roosting harlequins were observed on islets and rocky points in the estuary. USFWS counted 75 harlequins in this vicinity in 1992. Five harlequins were observed flying up the stream at the time of our observation in 1993. We counted an additional 50 harlequins on Shields Point, north of the mouth of Pauls Creek. Pauls Creek connects three lakes in the drainage (Pauls Lake, Laura Lake, Gretchen Lake).

Stream enhancement work was conducted in this drainage by USFS beginning in the 1950s. Fike nets are placed in the stream from May 15-June 30 to sample outmigrating smolt salmon. However, these nets do not block the stream. Two fish ladders/weirs are located in the lower reaches of this stream. A weir/fish pass is located in the Gretchen-Laura Lakes area which may form a potential hazard to harlequin ducklings. Another steep pass with a weir/fish ladder is located between Pauls Lake and Laura Lake. Sockeyes spawn in the Pauls-Laura Lake complex, as well as pink salmon, steelhead, and Dolly Varden.

Stream substrate at the site of investigation was bedrock and boulders, forming a deep-fast, boulder run. Channel type was curved and the stream was clear. Bank composition was a tree/shrub mosaic. The forest age class was old-growth and was unharvested in the lower reaches, although logging has taken place near and in the drainage above Gretchen Lake. The distance from Pauls Lake (the first lake) to the estuary is about 100 m. The lake is connected to the estuary by a deep and narrow 2-5 m channel draining the lake to the intertidal. The flow rate was approximately 10 cfs with a depth of 1.5 m in a channel 50 m from the estuary. The sideslopes at the lake entrance are distant. Harlequin broods may fledge on the series of large lakes in this drainage in which silver and red salmon spawn.

Phoenix Bay Creek. ASC #251-82-10086. This small, slow stream is located at the head of semi-enclosed Phoenix Bay on the east side of Perenosa Bay. Phoenix Bay is found north of Pauls Bay on northern Afognak Island. No harlequins were observed in Phoenix Bay on June 4. The stream is located in a flat, wet bog at the southeast end of the bay. This stream is not lake-fed and the flow is meandering, sluggish and slow. The bank vegetation is boggy humus, with scattered stunted spruces and low forbs, grasses and mosses. This is not typical boulder/riffle/run habitat usually selected by harlequin ducks for breeding, and this creek was rated poor (rated less than 1). The aspect of the stream mouth is NW. The channel type is curved and winding. The sideslopes of lower reaches of this stream are distant. The stream is clear, but discolored by tannin. The stream substrate is cobble, and the stream habitat is shallow-slow. The marine habitat is a protected bay with very limited estuary development. The forest in the vicinity is old growth, but is made up of scattered pole-type timber. The overstory is completely open. At the mouth, the stream width was approximately 5 m and depth was 50 cm. Bear and elk use of this open valley apparently is heavy. The valley connects to Seal Bay to the southeast and serves as a migration corridor for these large mammals. Silver salmon rearing occurs in the stream, but there is no other salmon use.