STATE OF ALASKA

DEPARTMENT OF FISH AND GAME

Division of Commercial Fisheries
Division of Sport Fish

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MEMORANDUM

TO: John Hilsinger, Director
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Charles Swanton, Director
Division of Commercial Fisheries

FROM: Jeff Regnart, Regional Supervisor, Region II
Ron Josephson, Regional Supervisor, FMPD
Division of Commercial Fisheries

James Hasbrouck, Regional Supervisor,
Region II
Division of Sport Fish

DATE: April 19, 2010

SUBJECT: Prince William Sound Permit Alteration Requests

Background

This memo summarizes regional and area staff comments related to enhanced salmon permit alteration requests (PARs) submitted for consideration at the spring 2010 Prince William Sound (PWS) Regional Plan Team meeting. In 2010, Prince William Sound Aquaculture Corporation (PWSAC) submitted a set of PARs to increase permitted capacity for pink, chum, and sockeye salmon. The PARs request:

(a) an increase of 103 million (22%) pink salmon eggs spread through three hatcheries, this increase is an overall increase of 15% of enhanced pink salmon production within Prince William Sound;

1. Cannery Creek: increase pink salmon egg take from 152 million to 187 million;
2. Armin F. Koernig: increase pink salmon egg take from 162 million to 190 million;
3. Wally Noerenberg: increase pink salmon egg take from 148 million to 188 million;

(b) an increase of 17.4 million (100%) chum salmon eggs at Armin F. Koernig (AFK) hatchery;

1. Armin F. Koernig: increase chum salmon release from 17 million to 34 million;

(c) an increase of 2.2 million (22%) sockeye salmon eggs at Main Bay Hatchery;

1. Main Bay: increase sockeye salmon egg take from 10.2 million to 12.4 million;

(d) sockeye salmon increased stocking for Crosswind Lake of 2 million (20%) fry, increased stocking for Summit Lake of 1.5 million (25%) fry, and increased stocking for Paxson Lake of 2 million (33%) fry;

1. Gulkana – Crosswind Lake: increase sockeye salmon fry from 10 million to 12 million;
2. Gulkana – Summit Lake: increase sockeye salmon fry from 6 million to 7.5 million;
3. Gulkana – Paxson Lake: increase sockeye salmon fry from 6 million to 8 million;

(e) proposed stocking for Monsoon Lake (1 million fry) and Ten Mile Lake (1.5 million fry). (for detailed department comments on items "c" and "d" see Attachments 1 and 2)

PAR Review Criteria

Department staff conducted a broad review of these PARs based on the following basic fisheries science and management criteria: genetics, pathology, fishery management, straying, regulatory, enhancement planning, and allocation. Some criteria were derived from enhancement planning documents such as the PWS/Copper River Phase 3 Comprehensive Salmon Plan (Phase 3 Plan), as well as from department policies and regulations.

Fisheries Management (Attachment 3)

The department's primary focus in this review is as the agency responsible for managing salmon fisheries in PWS. Our obligation to manage wild stocks in PWS is very challenged at current levels of production. Wild stock harvest has been unavoidable in the conduct of fisheries intended to target hatchery returns. While a lesser concern, we also mention fishery congestion and disruption of traditional fisheries that has occurred. Three of PWSAC's hatcheries are located in primary wild stock migration corridors and all four PWSAC hatcheries are sited in close proximity to numerous wild stock streams susceptible to localized depletion. The hatcheries produce multiple salmon species with run timings that span the entire wild stock season from early June through October. Run timing overlap between wild and enhanced fish cause fisheries targeting hatchery fish to operate in migration corridors during the entire run of wild pink, chum, and sockeye salmon. Migration corridor location and run timing overlap limits the number of management options to control harvest. Limiting fishing time and area are the primary methods for controlling wild stock harvest. In many cases, fishing outside hatchery terminal areas is minimal. Area restrictions have proven only partially effective at limiting wild stock harvest; wild stock salmon are still caught at various levels in the most restrictive scenarios. At times, unintended harvest results in escapement shortfalls. We expect that wild stock harvests will increase with higher production levels, resulting from the increased fishing effort required to harvest additional hatchery returns. Thus, the PAR production increases will likely require decreased fishing area to maintain acceptable harvest rates on wild salmon stocks. The current participation level for active set and drift gillnet permits and the increasing trend in active purse seine permits, combined with wild stock harvest concerns, will likely result in increased fleet congestion and conflict as management necessitates terminal area fisheries. Inability to limit wild stock harvest compromises department effectiveness in achieving escapement goals while harvesting large hatchery runs (>3 million chum and >15 million pink salmon, respectively).

Straying Effects on Escapement Goals and Management (Attachment 4)

Straying of enhanced salmon has negative implications for wild salmon escapement goal management. The department manages for wild salmon escapement goals in PWS based on aerial survey fish indices in streams. Because it is not possible to differentiate between wild and hatchery salmon during aerial surveys, all salmon are assumed to be wild. The presence of large proportions of stray hatchery fish in index streams inflates wild stock escapement estimates. Department staff are currently reconstructing past escapements to re-evaluate existing wild stock escapement goals given the observed number of hatchery strays.

Because hatchery stray proportions cannot be determined during inseason aerial surveys, management decisions that open commercial fishing may occur prior to obtaining sufficient wild stock escapements. In 2009, otoliths from salmon carcasses sampled in streams throughout PWS contained an unweighted average of ˜18% hatchery pink salmon strays and ˜14% hatchery chum salmon strays. It is clear that stray hatchery salmon are inflating wild stock escapement estimates and influencing management decisions. This impairs the department’s ability to meet statutory and regulatory requirements to manage for the sustained yield of wild salmon as the highest priority.

Hatchery Salmon Straying (Attachment 4)

Department staff has additional concerns associated with hatchery salmon straying. Department straying studies suggest at current production levels, hatchery salmon straying may pose an unacceptable risk to wild salmon stocks. Large scale hatchery salmon straying has negative implications on wild stock escapement management, ecological interactions, and genetic criteria. Studies conducted by the department since 1997 have documented significant proportions of hatchery pink and chum salmon within wild stock stream populations (Table 1). There are also high proportions of hatchery salmon in historically significant wild stock streams not immediately adjacent to hatcheries. Proportions of hatchery pink salmon in excess of 50% are documented in wild stock streams more than 35 km from the release site. Intermingling of hatchery and wild salmon potentially causes harmful genetic and ecological impacts to wild salmon stocks (see attached comments). Beyond genetic concerns, large numbers of stray hatchery fish have ecological effects on wild fish. Extensive research findings show negative density dependant and competitive interactions between wild and enhanced salmon.

Genetics (Attachment 5)

The Genetics Section of the department opposes increases in release numbers of chum salmon and pink salmon in PWS because of the high levels of straying of hatchery-produced fish into wild spawning populations for both species. Increases in production should not be considered until additional information is available about whether these levels of straying affect the genetic structures of wild populations in PWS. This recommendation is based on the assumption that larger stray rates produce proportionately larger amounts of introgression. However, the level of straying from hatcheries into wild spawning areas may not necessarily translate directly into rates of introgression. Allowing increases in the proportions of hatchery strays into streams is not consistent with the department's mission to manage on the sustained yield principle.

Based on a smaller set of data, sockeye straying has not been as significant as pink and chum salmon. However, a large variation in straying into Eshamy Creek of hatchery sockeye salmon has been documented. Straying rates of hatchery-origin fish into Eshamy Creek were estimated to be below 2% in three of four years. However, in 2007, the proportion of hatchery strays in Eshamy Creek was 22% (287 fish inspected). The Main Bay PAR could be conditionally supported, pending three requirements, because small stray rates were detected in three of four years. We suggest a rationale be developed and implemented for how the hatchery could be operated or the fishery prosecuted so that high levels of straying (>2%) do not occur. Second, escapement into Eshamy Creek would be sampled each year to verify that high levels of straying are not occurring. Third, straying data would be reviewed after five years to determine whether these actions were producing low straying rates. At the end of five years, this PAR would expire and a new PAR would be reviewed by the department. This PAR would be supported only if these requirements were met.

Allocation (Attachment 6)

Although the department considers allocation a lower priority in our assessment of these PARs, we do point out that, if approved, these PARs will likely aggravate the current allocation imbalance. The importance of PWS allocation balance is identified in Alaska Board of Fisheries findings, the Phase 3 Plan, and PWSAC's Allocation Policy (this plans calls for an allocation of a 50/50 split of the value of enhanced Prince William Sound salmon stocks). The current 5-year average PWS allocation is 62% seine and 38% drift gillnet (combined exvessel value $110 million). PWSAC projects these PARs will annually add $6.2 million to the seine fishery, while adding $2.2 million to the drift gillnet fishery. If approved, the PARs would increase the current allocation imbalance between purse seine and drift gillnet permit holders. The current allocation plan will likely be inadequate to balance the disparity if these production increases are approved.

Phase 3 Comprehensive Salmon Enhancement Plan

The plan covers a lot of aspects related to increased hatchery production that suggest a desire for more salmon, but there are also cautions that address some of the concerns that we have with most of PWSAC's PARs. For one, we point to the Production Recommendations section of the Phase 3 Plan, which states, "*The current level of enhanced salmon production returning to hatchery facilities has added to the complexity of managing the wild salmon mixed stock fishery. Consequently, the Phase 3 Plan does not recommend significant increases in adult returns to these facilities. Rather, the plan points towards opportunities that may be provided in various remote release locations throughout the Prince William Sound. A remote release location may involve the same impacts and concerns as would the establishment of a hatchery facility at that location.*" The department's position is that the complexity of managing current production levels is sufficiently challenging without adding increased production.

Recommendations

In summary, department staff opposes these PARs; however, the RPT meeting is a public meeting and we will consider additional information provided before or at that meeting. Based on the above review criteria, the PARs pose an unacceptable risk to wild salmon stocks, increase fishery congestion, and disrupt traditional fisheries. Detailed comments from all reviewers on the specifics of those concerns are attached.

Density dependent survival and growth (Attachment 7)

As a postscript to this memo we suggest that the proposed increases of hatchery production in PWS cannot be viewed in isolation. Rather, a large suite of ecological and economic tradeoffs must be considered, with a growing body of evidence suggesting hatchery salmon production could come at a substantial cost to other fisheries and wild salmon stocks. Many studies have concluded there is inter and intra-specific competition for pink and chum salmon food resources in North Pacific Ocean nearshore and offshore waters. This competition has been linked to a substantial decrease in productivity and body size of PWS pink salmon wild stocks.

Attachment 1 (Gulkana PAR Review)

STATE OF ALASKA

DEPARTMENT OF FISH AND GAME

DIVISION OF COMMERCIAL FISHERIES

SARAH PALIN, GOVERNOR

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March 19, 2009

TO: Ron Josephson
Section Chief
Fisheries Monitoring, Permitting and Development

FROM: Bert Lewis
Region II Resource Development

SUBJECT: Gulkana PAR

This Prince William Sound Aquaculture (PWSAC) Permit Alteration Request (PAR) requests an increase in the allowable sockeye salmon fry stocking levels from the Gulkana Hatchery (GH) system. The PAR proposes to increase stocking for Crosswind Lake by 20% (10 million to 12 million), Summit Lake by 25% (6 million to 7.5 million) and Paxson Lake by 33% (6 million to 8 million). PWSAC also requests to stock sockeye salmon fry into Monsoon Lake (1 million) and Ten Mile Lake (1.5 million) as needed. The additional fry for the increased stocking are from surplus production meant to compensate for losses due to IHNV outbreaks. These fry are normally destroyed if there are no losses due to IHNV. PWSAC requests the increased stocking to compensate for an envisioned decrease in future returns based on a four year (BY 2000-2003) downward trend in overall fry-to-adult survivals. PWSAC contends that the decrease in fry-to-adult survivals is due to predator abundance within nursery lakes and downstream rivers.

Department staff recommend the denial of this PAR based on multiple areas of concern. Detailed comments from all reviewers are attached. A genetics review finds that this PAR has clear potential to damage the Copper River sockeye salmon genetic resource. Pathology identified areas of concern for the potential increase of disease transmission. Stocking Monsoon and Ten Mile lakes places sockeye salmon up-stream of Chinook salmon spawning grounds, potentially increasing exposure of these salmon to the IHN virus. Sport Fish Division finds no evidence that predation has increased or any link to the purported decreased enhanced sockeye salmon survival. Some the purported decrease may be an artifact of mortality associated with the initiation of the strontium marking program. Management of Copper River sockeye salmon escapement is complicated by large returns of enhanced fish (see 2005 Ashe memo and Hollowell comments for more detail).

ALASKA DEPARTMENT OF FISH AND GAME

DIVISION OF SPORT FISH

MEMORANDUM

TO: **Bert Lewis**

DATE: February 24, 2009

FROM: **Mark A. Somerville**
Area Management Biologist

TELEPHONE: 907-822-3309

SUBJECT: Gulkana PAR

Thank you for the opportunity to review Prince William Sound Aquaculture Corporation's (PWSAC) Permit Alteration Request (PAR) for the Gulkana Hatchery. The PAR requests an increase in the allowable stocking levels for Crosswind Lake by 20% (10 MM to 12 MM), Summit Lake by 25% (6 MM to 7.5 MM) and Paxson Lake by 33% (6 MM to 8 MM). PWSAC also requests to stock sockeye in Monsoon Lake (1 MM) and Ten Mile Lake (1.5 MM) as needed. The additional fry for the increased stocking would come from surplus production meant to compensate for losses due to IHNV outbreaks. These fry are normally destroyed if there are no losses due to IHNV. PWSAC requests the increased stocking to compensate for an envisioned decrease in future returns based on a four year (BY 2000-2003) downward trend in overall fry-to-adult survivals. PWSAC contends that the most significant likely cause for the downturn in fry-to-adult survivals is predator abundance within the three current nursery lakes and their respective downstream rivers. They contend that the numbers of lake trout and gulls have increased based on observed feeding by these predators during the spring outmigration period. Furthermore, PWSAC believes that individual size and abundance of lake trout has increased significantly within Crosswind Lake.

I recommend denial of the PAR. PWSAC has not demonstrated that current production and levels of out-stocking will be insufficient to meet the Gulkana Hatchery Basic Management Plan objectives for adult returns. There have been no abundance assessments of lake trout in Crosswind or Summit lakes and the last abundance estimates for Paxson Lake were obtained for 2003-2004. The statewide harvest survey does not indicate an increased catch rate for lake trout in these lakes. Therefore, claims that lake trout populations within these lakes have increased are unsubstantiated. Assumptions that predation levels have increased in Crosswind and Summit Lakes run counter to the observed, above average fry-to-smolt survival in these lakes for the past two brood years (2005 & 2006). Secondly, no studies have been conducted to ascertain the causes for annual fluctuation of fry-to-smolt survival in nursery lakes.

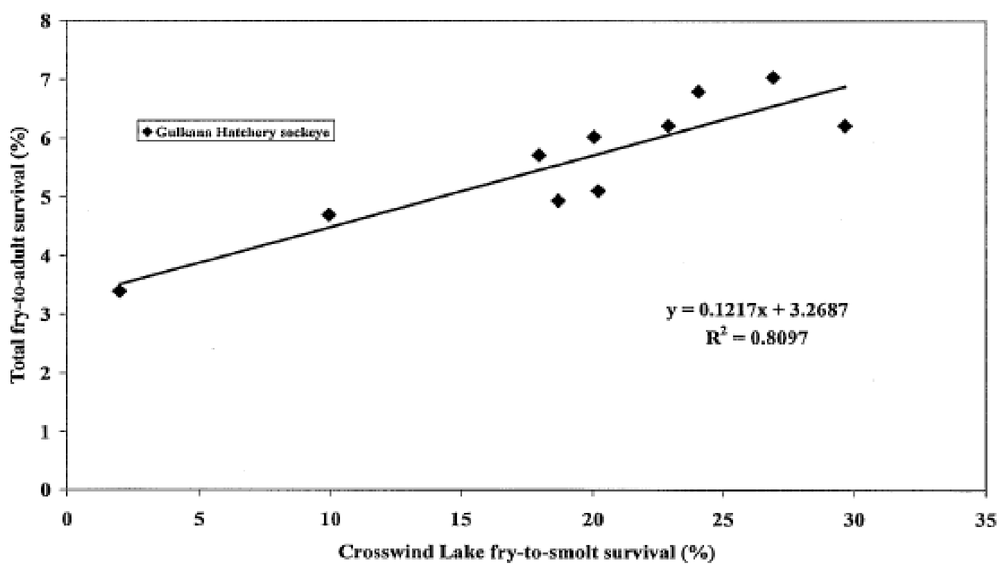
No comprehensive studies have been conducted on the effects of sockeye stocking in Crosswind and Summit lakes. This includes impacts on the plankton and invertebrate populations in these lakes and the interspecific competition for food resources between juvenile sockeye and juvenile resident fishes including lake trout, burbot, whitefish and Arctic grayling. Therefore, the effects (either good or bad) of stocking sockeye salmon in Monsoon and Ten Mile Lakes on the resident fish populations of those lakes can not be predicted. The most significant king salmon spawning in the West Fork Gulkana River occurs below Monsoon Lake. In the Middle Fork Gulkana River, significant king salmon spawning occurs below Dickey Lake and within the lower reaches of Hungry Hollow Creek. Creating a return of adult sockeye to Monsoon and Ten Mile lakes, that may impact known spawning populations of wild king salmon stocks, is contrary to the Sustainable Salmon Policy (5 AAC 39.222(1)(D)).

I recommend denial of increased stocking levels for Crosswind, Summit and Paxson lakes, based on the following:

1. PWSAC has failed to demonstrate that a need exists to increase sockeye salmon production in the Copper River drainage. It has failed to demonstrate that current hatchery production will be insufficient to meet the management plan objectives. Use of the recent four year fry-to-adult survival average is a simplistic modeling technique for projecting the upcoming year's return with generally broad confidence intervals. The use of such an average for projecting long-term return trends is misleading and statistically incorrect.

    a. For the past 10 years (BY 1994 – 2003) total fry-to-adult survival for Gulkana sockeye salmon appears to be directly correlated to the fry-to-smolt survival in Crosswind Lake (Figure 1). Although total Gulkana fry-to-adult survival has shown a downward trend from BY 2000 – 2003, this trend is mainly due to two weaker than average (previous 10 years) brood years (2002 and 2003). Fry-to-smolt survival in Crosswind Lake for BY 2004 was also below the previous 10-year average. However, survival of brood years 2005 and 2006 were both above the previous 10-year average and indicate a potential for increased fry-to-adult survivals in return years 2009-2011.

Figure 1. Total Gulkana Hatchery fry-to-adult survival as a function of Crosswind Lake fry-to-smolt survival for broodyears 1994 to 2003 (survival percentages are arcsin transformed).

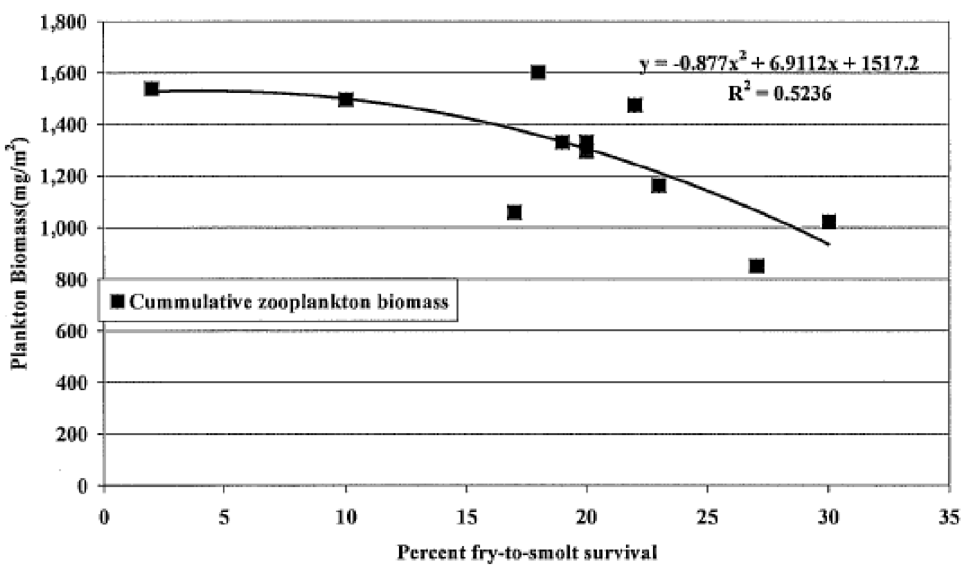


2. PWSAC has presented no other alternatives to achieve increased survival of hatchery salmon such as longer term rearing within the hatchery or alternative out-stocking methods for current nursery lakes.

3. No studies have been conducted to assess the effects of predation on stocked sockeye fry in Crosswind, Summit or Paxson lakes. These lakes contain lake trout, burbot and whitefish which are all capable piscivorous predators. In addition, no studies have been conducted on the effects of competition between juvenile sockeye salmon and juvenile burbot, lake trout, and whitefish.

4. Available data on Crosswind Lake indicate that as fry-to-smolt survival increases, seasonal biomass of zooplankton appears to decrease (Figure 2). Although the trend is weak, it indicates that current stocking levels may have the ability to significantly reduce zooplankton biomass and that survival of fry may be primarily determined during the first summer of residency in the lake. Survival of stocked salmon fry in their first three months of lake residency depends on several possible influences, but no studies have been conducted to identify which of these influences may be significantly affecting sockeye fry survival.

Figure 2. Cummulative zooplankton biomass from June through early October in Crosswind Lake compared with arcsin transformed fry-to-smolt survival proportions of hatchery stocked sockeye fry from broodyears 1996-2005



5. There has been no abundance estimate made for lake trout in Crosswind or Summit lakes and no abundance estimates in Paxson Lake since 2003-2004. The most recent estimates for Paxson Lake indicate the lake trout population has remained stable when compared to estimates from the early 1990's. The studies did not indicate any increase in size in the lake trout in Paxson Lake and it would be assumed that the same population characteristics have been maintained in Crosswind and Summit lakes. Statewide Harvest Survey data do not indicate an increased trend in catch or

harvest of lake trout from Crosswind, Summit or Paxson lakes. Finally, anecdotal information from anglers does not indicate increased catch or harvest of lake trout or burbot from these lakes nor has it indicated an increased size of the fish being caught.

6. Lake trout in Crosswind Lake are managed under the principles of the Wild Lake Trout Management Plan (5 AAC 52.060 (c)(1 & 2). The size limit of 24" was imposed to allow lake trout to spawn at least once before becoming vulnerable to harvest. In addition, the size restriction limits harvest to sustainable levels. Lake trout in Crosswind Lake (or Paxson and Summit lakes) are not managed as a "trophy' fishery, but to maintain harvests at sustainable levels based on the area of the lake.

I recommend denial of stocking Gulkana Hatchery sockeye fry into Monsoon and Ten Mile lakes, based on the following:

1. Stocking sockeye salmon in Monsoon and Ten Mile lakes would place a potentially large number of spawning condition sockeye directly up-stream of important king salmon spawning grounds. This situation would increase exposure of these king salmon to the IHN virus. Creating a potential impact to known spawning populations of wild king salmon stocks is contrary to the Sustainable Salmon Policy (5 AAC 39.222(1)(D)).

2. Although sockeye fry have been stocked in Crosswind, Summit, and Paxson lakes the effects of these stockings on the pre-existing lake community of these lakes has never been studied. Although very successful, from a sockeye production standpoint, what effects (either beneficial or deleterious) has this success had on the resident sport and subsistence fishes of these lakes? Prior to increasing stocking levels in the current nursery lakes the interactions between stocked sockeye fry and the abundance, distribution and population characteristics of the resident fishes should be ascertained in those lakes. Prior to stocking new lakes with sockeye fry, the abundance, distribution and population characteristics of the resident fishes should be ascertained.

3. Ten Mile Lake is the headwater of Hungry Hollow Creek which is one of only three documented spawning locations for Gulkana River rainbow and steelhead trout.

4. Ten Mile Lake was stocked with sockeye salmon fry from 1973 to 1978. The success of these stockings was not mentioned in the PAR. Anecdotal information indicated that few if any adults returned to Ten Mile Lake. In addition, wild sockeye salmon stocks are present in Hungry Hollow Creek and nearby Dickey and Swede lakes (the outlet stream to Swede Lake is less than 5 miles from Hungry Hollow Creek). There is potential for a negative impact on these wild stocks by the proposed release in Ten Mile Lake.

5. Resident fishes such as grayling, lake trout and burbot are found in the Hungry Hollow system and Monsoon Lake. These are the same predatory species that are found in Crosswind, Paxson and Summit lakes. Stocking of sockeye salmon fry in Ten Mile and Monsoon lakes would expose stocked salmon fry to the same predation and reduced survival found in the other stocked lakes where predation is purported to be an issue.

From Chris Habicht
To: Bert Lewis (DFG)
Cc: Meyers, Theodore R (DFG); Somerville, Mark A (DFG); Templin, Bill D (DFG)

Feb 25, 2009

Hi Bert,

From a genetics point of view, I would recommend against this PAR. When reviewing PAR's for genetic concerns, I look at both the potential gain of the activity and the potential damage to the genetic resources.

In this case, the rationale behind the PAR for potential gain is weak: Mark Somerville provided a nice review of the issues associated with the applicant's rationale in his memo dated 2/24/09 on the Gulkana PAR. In summary: 1) the applicant says that they are not getting back the same proportion of fish released that used to and blames the decrease on predation, yet they show no evidence for this beyond anecdotal evidence. Even if the culprit is increased predation, why would they not expect predation to continue to rise in step with increased release numbers? 2) The applicant says that this PAR will ""provide an opportunity to gain insight on the magnitude of the predation forces on outmigrating smolt survival relative to other nursery lakes with larger predator populations", yet they provide no experimental design to test any hypotheses. Given the lack of an experimental design, it is unclear that they need to stock such large numbers of fish into previously unstocked lakes near wild sockeye salmon production.

On the other hand, there is clear potential to damage the genetic resource. Both new release sites are close to areas with wild spawning sockeye salmon and the numbers proposed for stocking into these lakes (1.0- and 1.5-million fry) and would likely affect current genetic structure. The stock used at the Gulkana Hatchery is likely adapted to different thermal incubation regimes than those near the release sites because the hatchery broodstock was developed from a population that used warm springs. Hybridization between the hatchery and wild stocks would likely disrupt the genetic adaptation of the wild stocks or, given the large numbers of fish stocked, supplant the indigenous population. Secondly, the large increases (20% to 33%) to the currently stocked lakes could increase straying if many more fish return to the release sites. Because the mechanism for the purported reductions in returns is not clear, predicting the effect of additional stocking on the numbers of returning adults is difficult.

Chris Habicht.

From: Meyers, Theodore R (DFG)

Feb 24, 2009

Hi folks,

Because sockeye salmon are apparently native to both Monsoon and Tenmile Lake systems the disease policy does not preclude transplanting more sockeye and allows the option for consideration on a case by case basis. That said however, part of the mission of the disease policy is also to prevent amplification of or increased exposure to an existing pathogen within any given stock of fish (i.e. the Chinook) if that stock is considered a significant resource. Increasing sockeye returns from 10-50 spawners up to 2,500 or 5,000 fish will certainly have the potential to negatively impact the few resident Chinook in these systems, not just in competition for spawning habitat but also with regard to increased exposure to IHNV or amplification of the presence of that pathogen. The same can be said for the lake trout in these lakes as they are susceptible to IHNV, albeit less so than sockeye and Chinook. Changing the status quo of a host and pathogen in a system by drastically increasing the number of sockeye and therefore IHNV has the potential to allow the virus to adapt to other susceptible non-sockeye species if they co-exist within the same system. This is an unacceptable situation the disease policy was designed to avoid at all costs but at the same time without being unreasonable.

Your call on whether these Chinook salmon and lake trout are important enough as resources to deny the PAR on disease concerns. I would have no issue with that decision.

Ted

Attachment 2 (Gulkana Limnology)

The following is a revised memorandum from March 2, 2010.

Department staff reviewed the limnological and fisheries data relative to the ongoing sockeye salmon fry stocking programs conducted by Prince William Sound Aquaculture Corporation (PWSAC) at Crosswind, Paxson, and Summit lakes with particular focus on stocking levels. Annual environmental variation affects fish growth, in conjunction with biotic factors such as fish density. Likewise, zooplankton production is related to physical and biotic factors, and as such, is only an indirect measure of sockeye smolt, and ultimately adult production. Since the relationship between stocking (fry) and zooplankton involves multiple factors, it seems most prudent to explore the various relationships between fry and smolt.

We updated an approximate comparison of the juvenile sockeye salmon forage base of Crosswind, Paxson, and Summit lakes by calculating the amount of food available, represented as the mean standing stock of macrozooplankton, per individual (stocked) fry (Figure 1). On average, there is a great deal more plankton food available to each sockeye fry in Crosswind Lake (5.5 g fry^{-1}) compared to either Summit Lake (1.6 g fry^{-1}) or Paxson Lake (2.6 g fry^{-1}), although the difference between Crosswind and Paxson since 2005 has been negligible. These data were some of the preliminary evidence used to reduce stocking levels following a review by the Central Region Limnology lab (Edmundson memo of March 10, 2000).

In recent years, stocking levels have been approximately 10 million at Crosswind and 6 million at Paxson and Summit lakes.

CROSSWIND LAKE

The composition of zooplankton species through time in Crosswind Lake has been stable for most periods. In 2004 however, in terms of percent total biomass, *Cyclops*, the dominant zooplankter, substantially decreased while *Diaptomus* increased (Figure 2a). The change in composition appears to be largely driven by the increase in *Diaptomus* abundance; *Cyclops* abundance remained stable (Figure 3). The zooplankton changes in 2004 do not appear to be tied to fry or smolt abundance, and in following years, the composition reverted back to more average levels.

For Crosswind Lake, there is no substantial change in body length through time for any of the major zooplankton species (Figure 4a). Similarly, median zooplankton biomass does not appear to have substantially changed through time (Figure 5). Mean annual zooplankton standing stocks have been relatively consistent and robust since the data sets began in 1992 (Figure 3). Additionally, there has not been an adverse (negative relationship) effect of fry abundance on mean zooplankton biomass (Figure 6).

There is little evidence of fry abundances having significant negative effects on smolt size, abundance, or fry-to-smolt survival (FSS). Smolt weight decreases slightly with increasing fry abundance, but not significantly (Figure 7a; a=0.10). The relationships between smolt abundance and FSS against fry abundance should be nonlinear, whereby at larger stocking sizes density dependence should be evident (i.e., a stock-recruitment model should fit the data). Figures 7b and

7c suggest that stocking levels have not been excessive because FSS or smolt abundance have not been reduced at large fry abundances. In fact, the greatest smolt abundance occurred at stocking levels greater than 9 million fry. Further support that stocking levels have not negatively impacted smolt abundances is evidenced by the insignificant (p=0.54) relationship of ln(smolt/fry) against fry abundance; this is equivalent to examining the ln(returns/spawner) versus spawner abundance in an adult Ricker stock-recruitment model. Indicators of fish forage pressure on zooplankton assemblage (species composition, size, and biomass) and fry-to-smolt relationships all suggest that stocking levels have not compromised Crosswind Lake sockeye fry rearing capacity.

PAXSON LAKE

The composition of zooplankton species through time in Paxson Lake has been stable for most periods (Figure 2b). In 2000, *Cyclops* abundance, the dominant plankter, substantially decreased (Figure 3b). This change does not appear to be tied to fry or smolt abundance; in subsequent years *Cyclops* abundance reverted back to more average levels. The amount of food available, (mean standing stock of macrozooplankton), per individual (stocked) fry (Figure 1) appears to have increased in response to the 2004 reduction of stocking levels from 12 million to under 6 million fry. This may be a response to reduced grazing pressure. However, the same response is not reflected in smaller scale comparisons by species or mean zooplankton biomass (Figures 3 and 5).

For Paxson Lake, there is no significant change in body length through time for any of the major zooplankton species (Figure 4b). Likewise, median zooplankton biomass does not appear to have any significant changes through time (Figure 5), although the last 3 years have shown an increase. Mean annual zooplankton standing stocks have been relatively consistent and robust since the data began to be collected in 1992 (Figure 3). Additionally, there has not been a significant effect of fry abundance on mean zooplankton biomass (Figure 8). In my view, the most meaningful relationships in terms of stocking levels include smolt information. For Paxson Lake, smolt information is lacking. Even without smolt information, the available indicators do not suggest that stocking levels have created density dependence in a manner that reduces rearing capacity of Paxson Lake.

SUMMIT LAKE

The composition of zooplankton species through time in Summit Lake has been stable for most time periods (Figure 2c). However, from 1997–2000 when fry abundances were highest (greater than 9 million), the species composition drastically changed. In 1997, 1998, and 2000 the percentage of *Cyclops* was greatly reduced, while for *Daphnia* and *Bosmina* there was an increase. Similarly, in terms of abundance, *Cyclops* decreased precipitously from 1997 through 2000, rebounding to previous levels after stocking levels were reduced (Figure 3). Dominant copepod zooplankton densities are likely reflective of a system with heavy juvenile sockeye salmon planktivory. *Daphnia* and *Bosmina*, larger and slower zooplankton species, are often the preferred food source for planktivorous juvenile salmonids. It is counter intuitive that these species increased during the period of highest stocking levels. However, the increased grazing pressure associated with high stocking levels is reflected in the sharp decline in *Cyclops* indicators.

For Summit Lake, there is no substantial change in body length through time for any of the major zooplankton species (Figure 4). Similar to the change in zooplankton species composition for this period, the years 1997-1999 having fry abundances greater than 9 million appear to be associated with a drop in median zooplankton biomass (Figure 5).

We modeled the relationship between stocking level and macrozooplankton biomass using linear and nonlinear regression. For the linear model, the coefficient of the slope is significant ($p<0.01$), recognizing that there is a large amount of unknown variation surrounding the regression line (Figure 9). Although previous reviews have modeled this as a linear relationship, to me it seems that a nonlinear model is more realistic. It seems unlikely that at low to moderate levels of fry abundance there would be a noticeable cropping effect like the linear model portrays. Rather, we suspect that zooplankton biomass would be largely unaffected by low to moderate levels of fry. Regardless, both models show strong evidence of cropping at higher fry abundances.

Smolt weight and FSS decrease with increasing fry stocking, indicative of a density dependent mechanism (Figures 10a and 10b). Additionally, a Ricker stock-recruitment model (with an autoregressive-1 parameter) fit to smolt abundance versus fry abundance suggests that the highest smolt abundances occur at stocking levels between 3 and 8 million fry. Crustacean zooplankton biomass, FSS, smolt weight, and ln(smolt/fry) in Summit Lake were all negatively (and significantly) related to the number of stocked fry.

In conclusion, we recommend the following: (1) maintain stocking levels in Summit Lake at the current permitted level of 6 million sockeye fry to minimize foraging pressure on the zooplankton community while optimizing FSS, and hence smolt abundances; (2) maintain current stocking levels at Crosswind and Paxson Lakes because they do not cause concern; and (3) continue the environmental, zooplankton and smolt sampling programs. Initializing a smolt abundance program at Paxson Lake would be especially useful in optimizing fry stocking levels. It should be noted that this review of stocking levels only considered the direct impact to zooplankton and sockeye salmon. It did not consider how other species in the lake such as whitefish, lake trout, or burbot could be affected. Information on these other species is often difficult and expensive to collect, but should be a consideration in any stocking program.

cc: Bosch, Botz, Brenner, Hollowell, Gray, Josephson, Lewis, Miller, Moffitt, Reggiani, Regnart, Somerville.

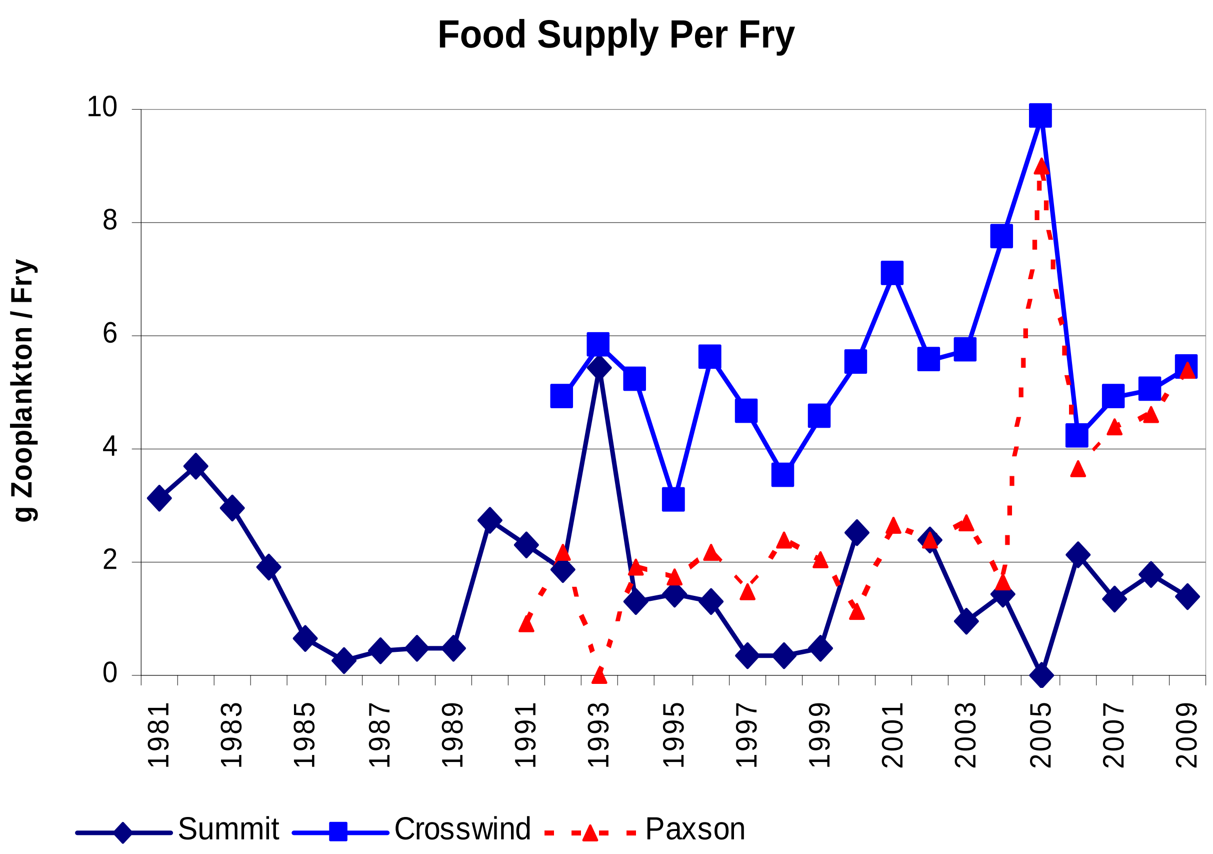


Figure 1. Annual food supply (g zooplankton per fry) for Crosswind, Paxson, and Summit lakes.

(a)

(b)

(c)

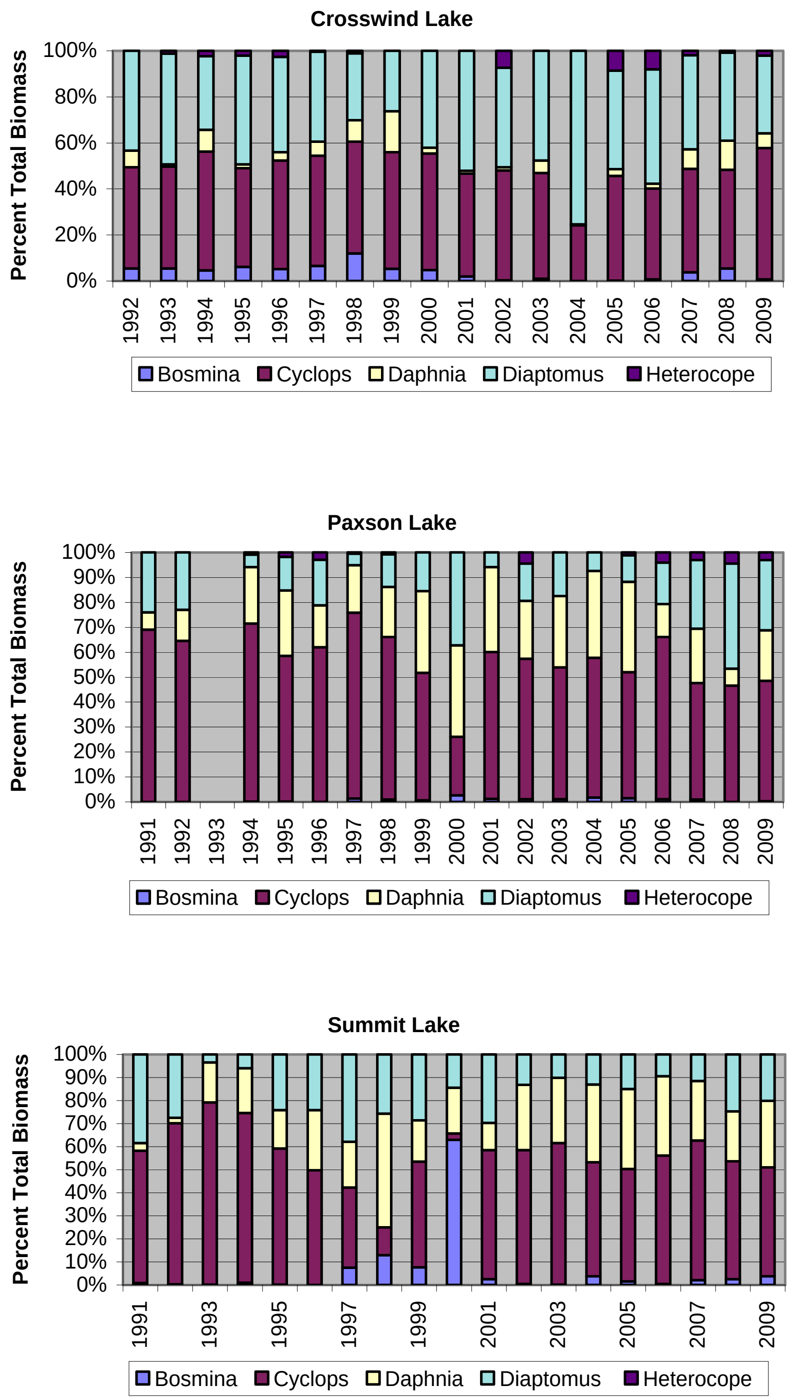


Figure 2. Zooplankton percentage of total biomass for Crosswind (a), Paxson (b), and Summit (c) lakes.

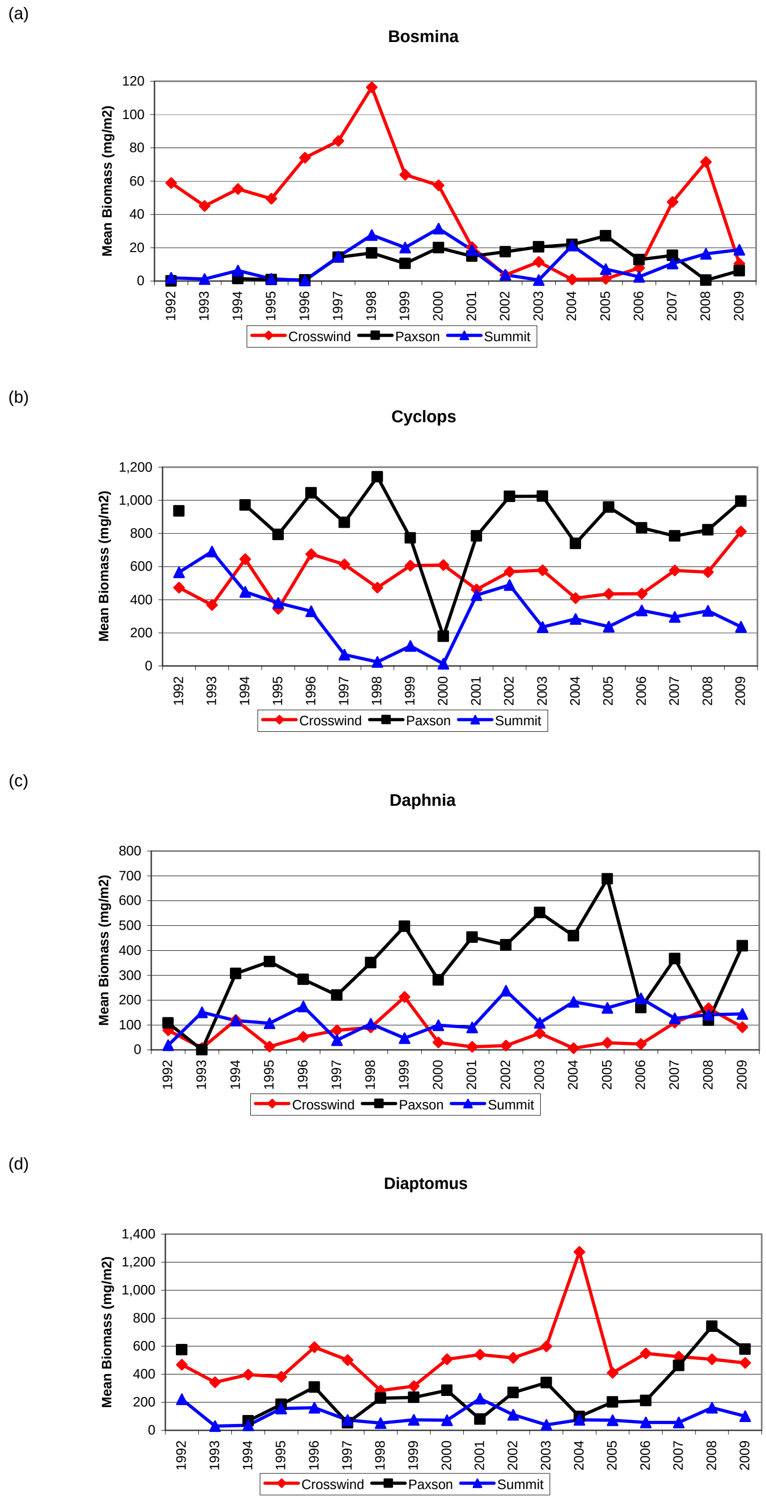


Figure 3. Mean biomass standing stock for *Bosmina* (a), *Cyclops* (b), *Daphnia* (c), and *Diaptomus* (d) in Crosswind, Paxson, and Summit lakes.

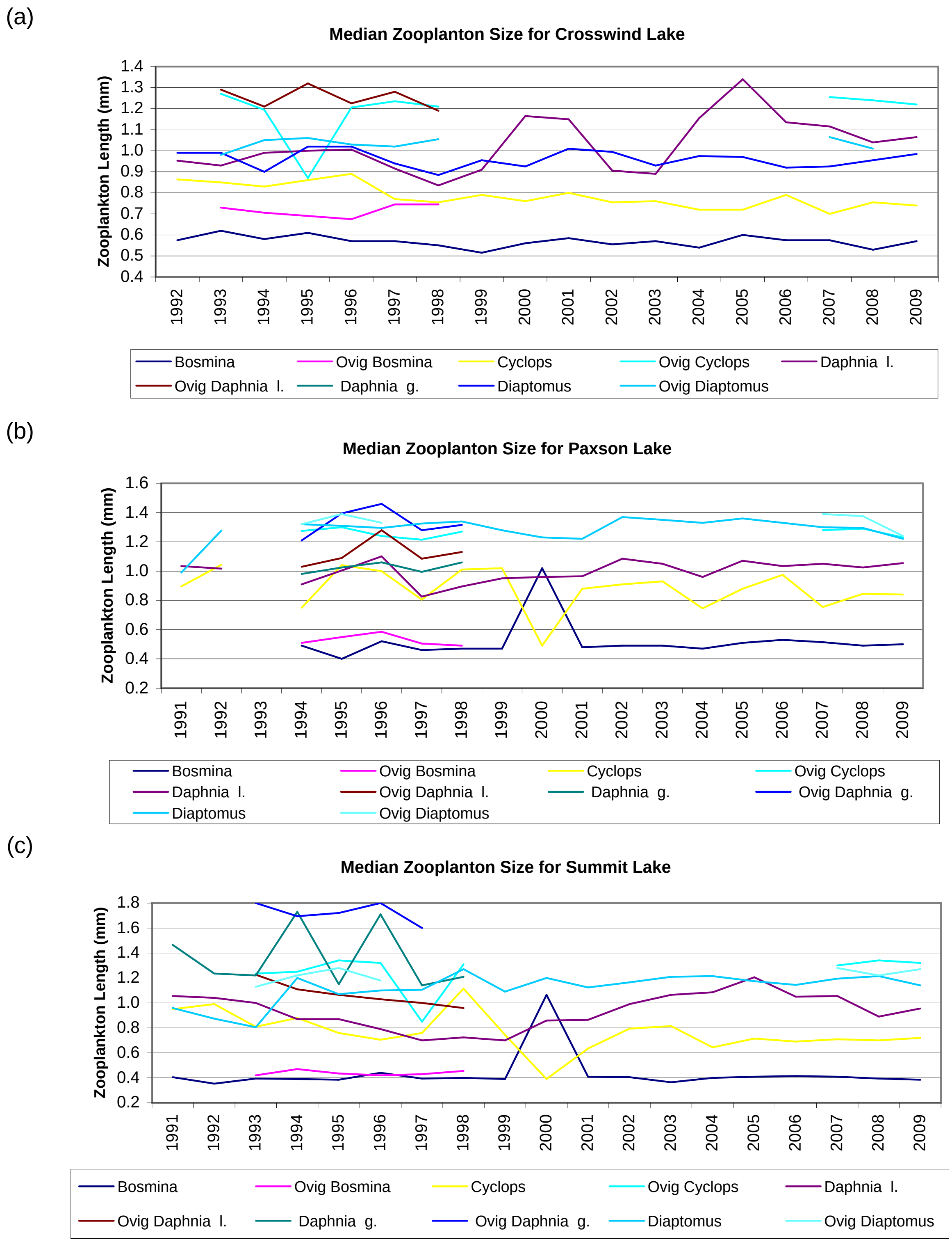


Figure 4. Median zooplankton size for Crosswind (a), Paxson (b), and Summit (c) lakes.

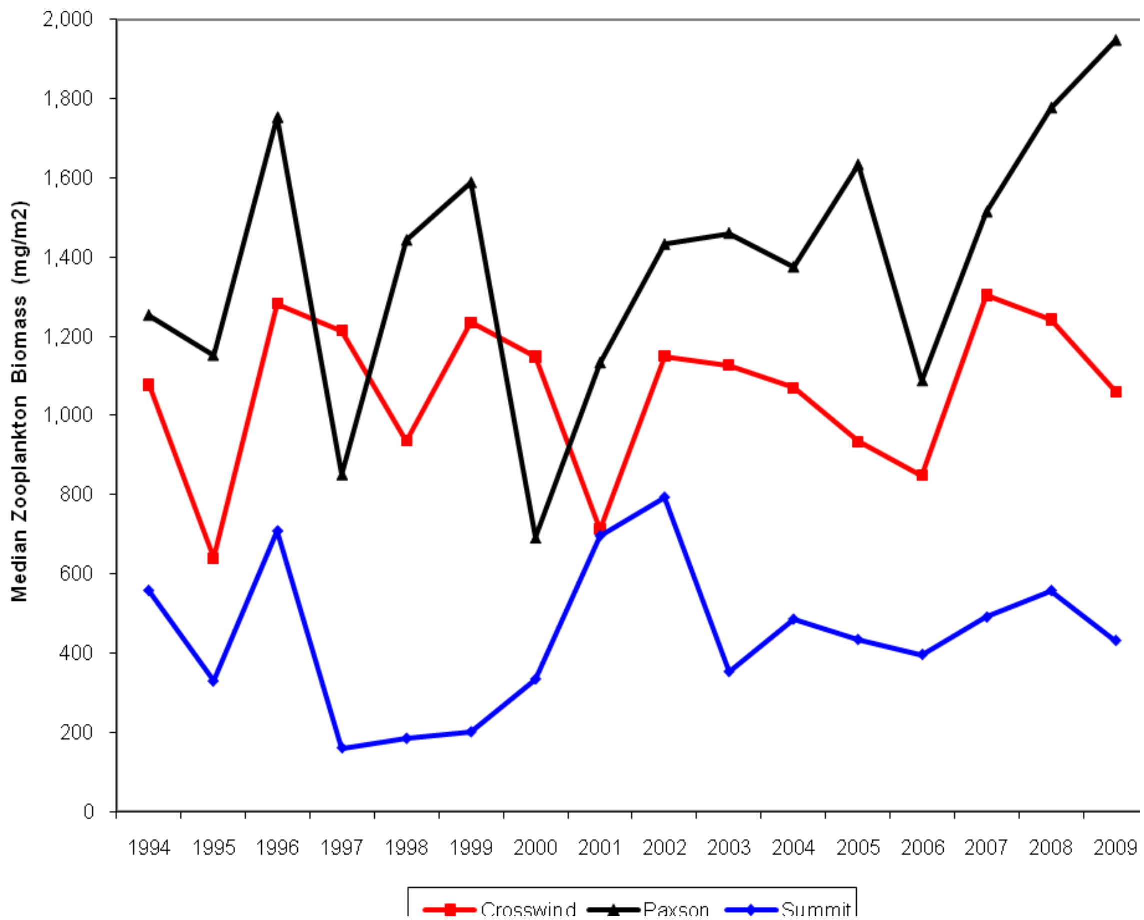


Figure 5. Median zooplankton biomass through time for Crosswind, Paxson, and Summit lakes.

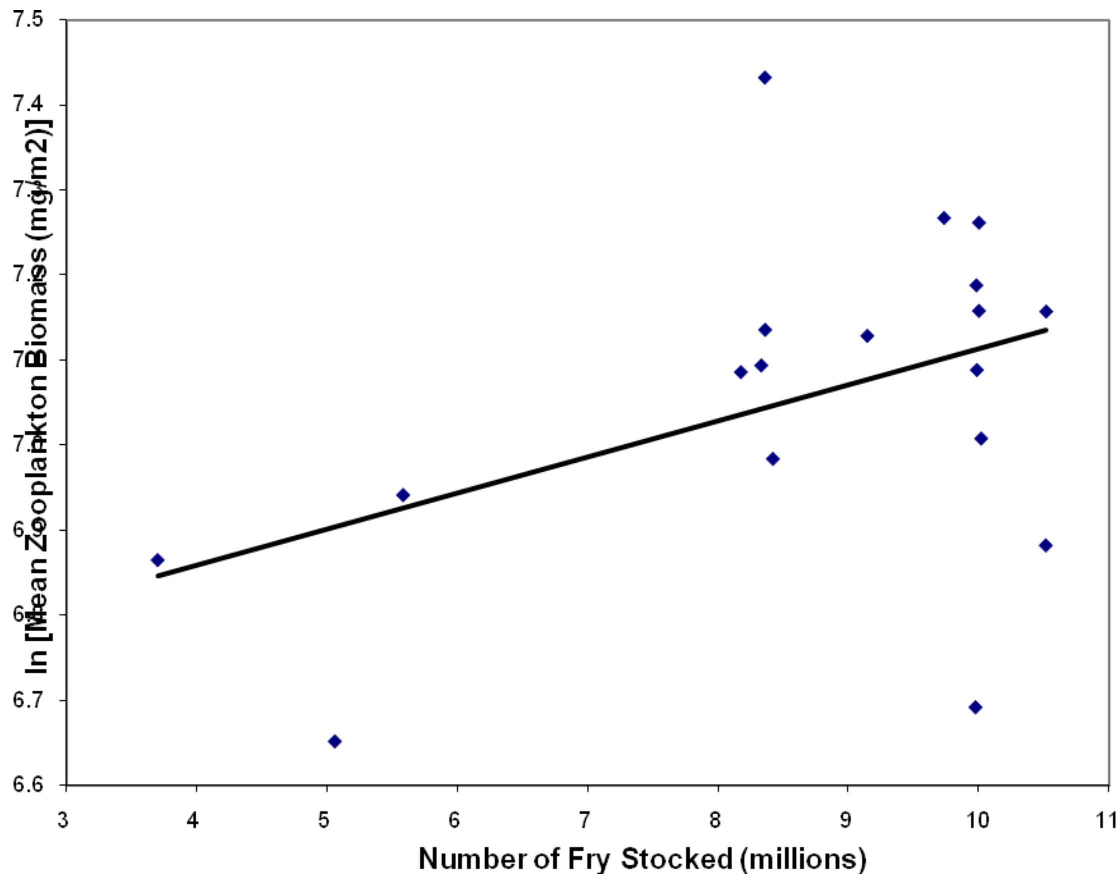


Figure 6. Mean zooplankton biomass versus the number of fry stocked in Crosswind Lake.

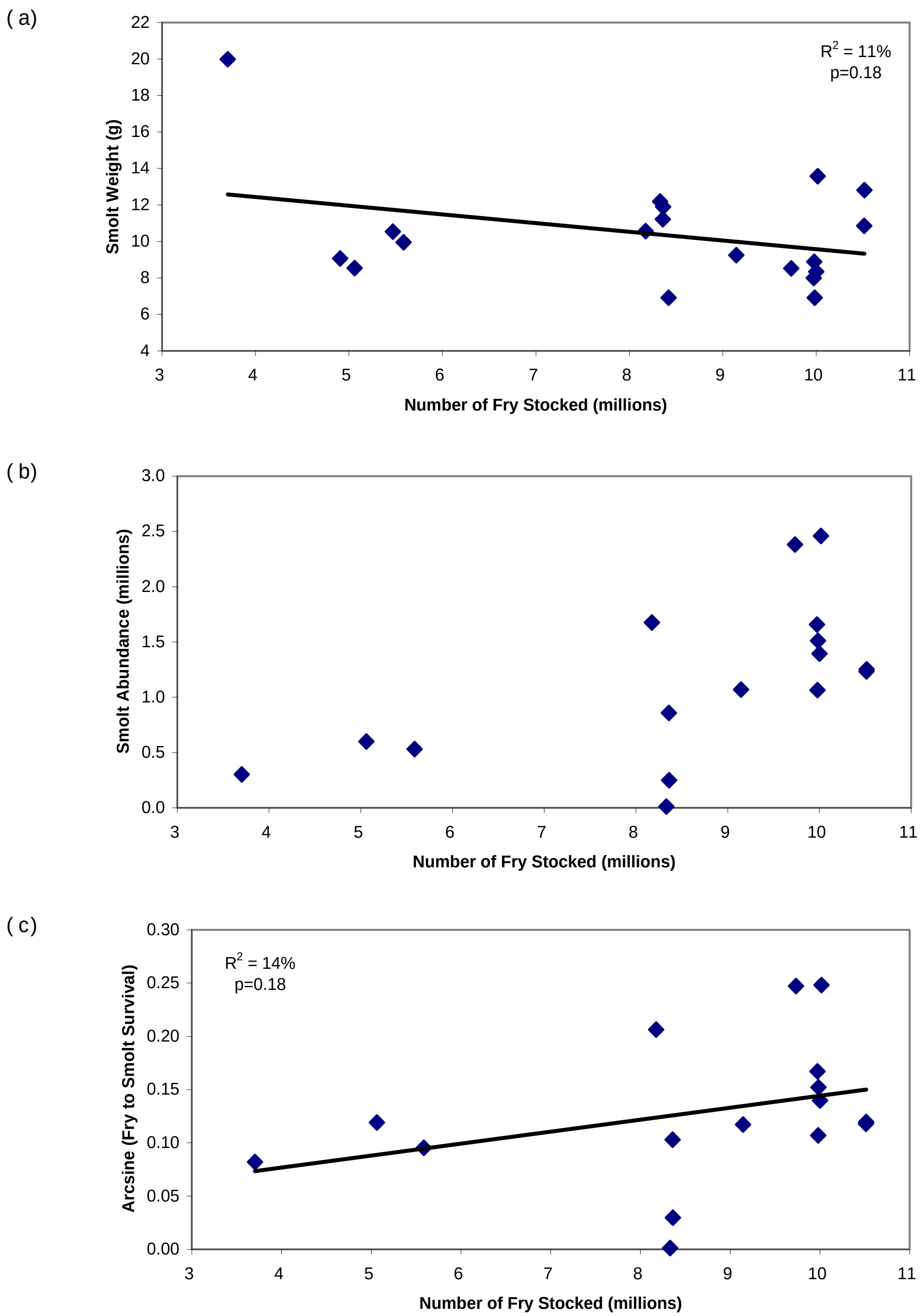


Figure 7. Smolt weight (a), abundance (b), and fry-to-smolt survival (c) versus stocking level for Crosswind Lake.

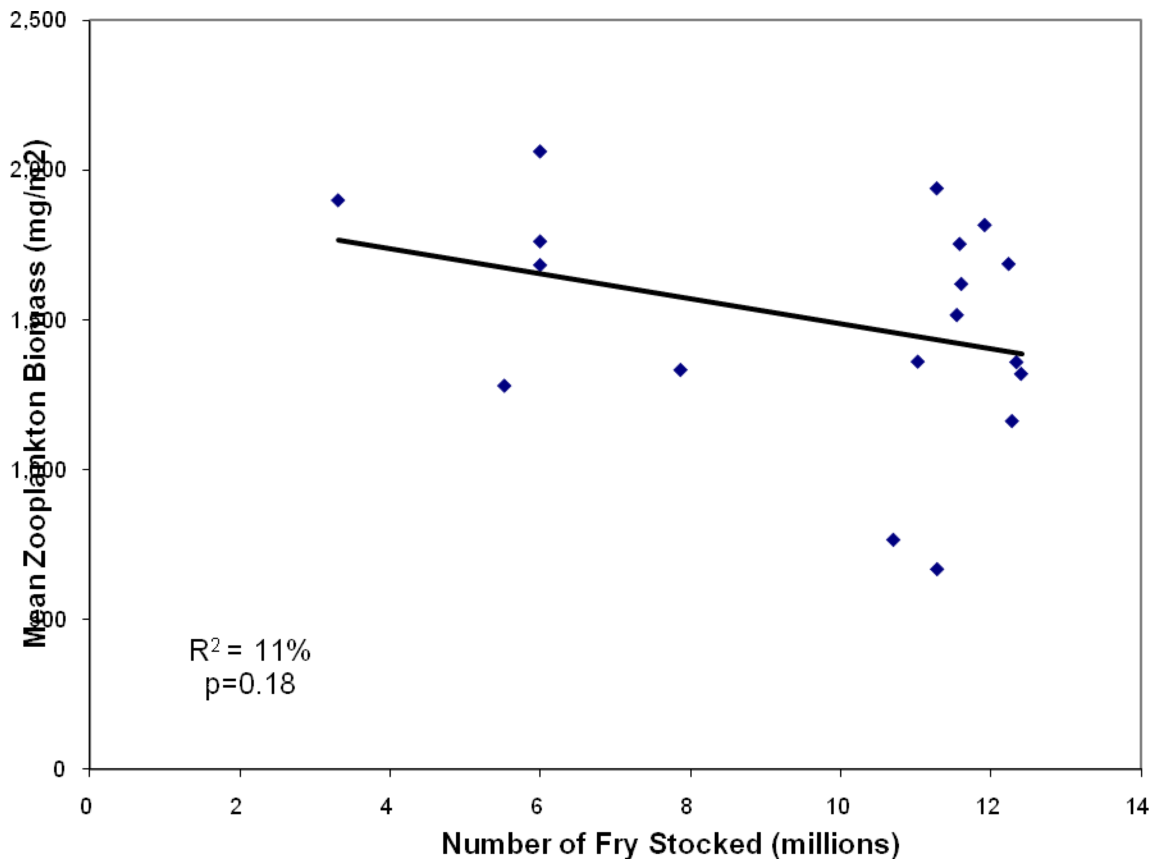


Figure 8. Mean zooplankton biomass versus the number of fry stocked in Paxson Lake.

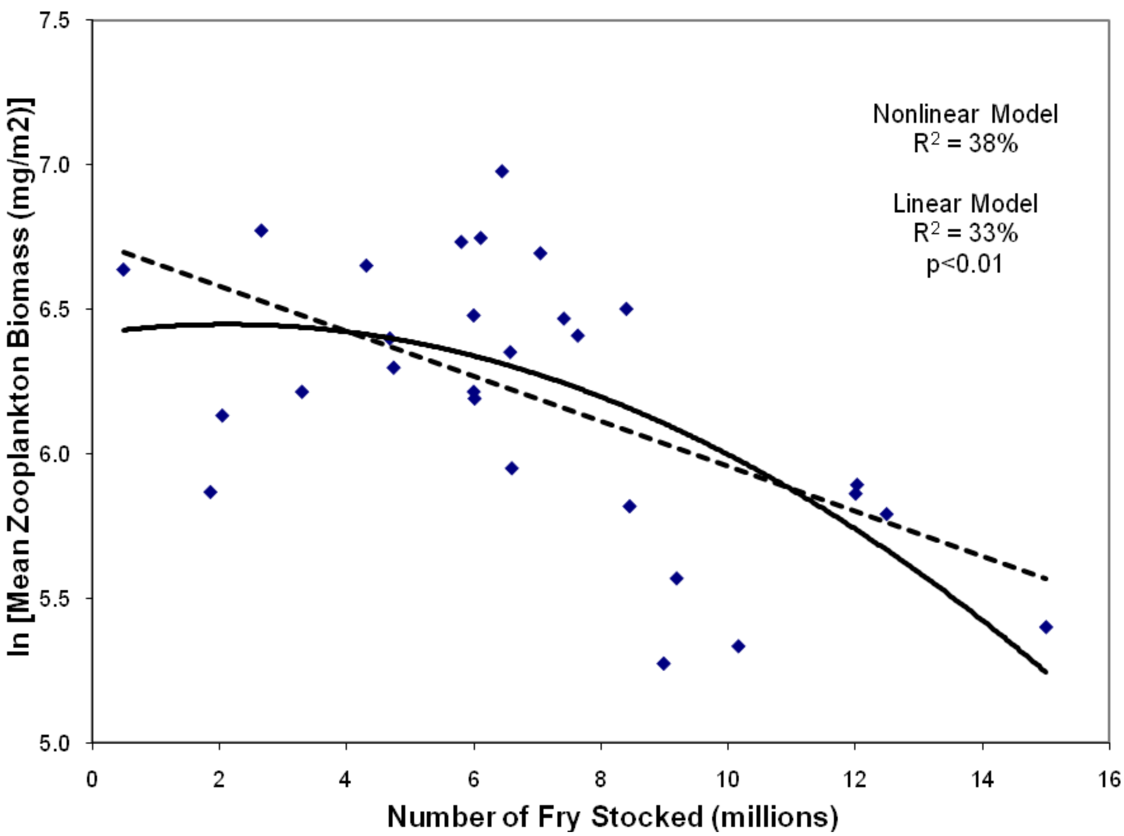


Figure 9. Mean zooplankton biomass versus the number of fry stocked in Summit Lake.

(a)

(b)

(c)

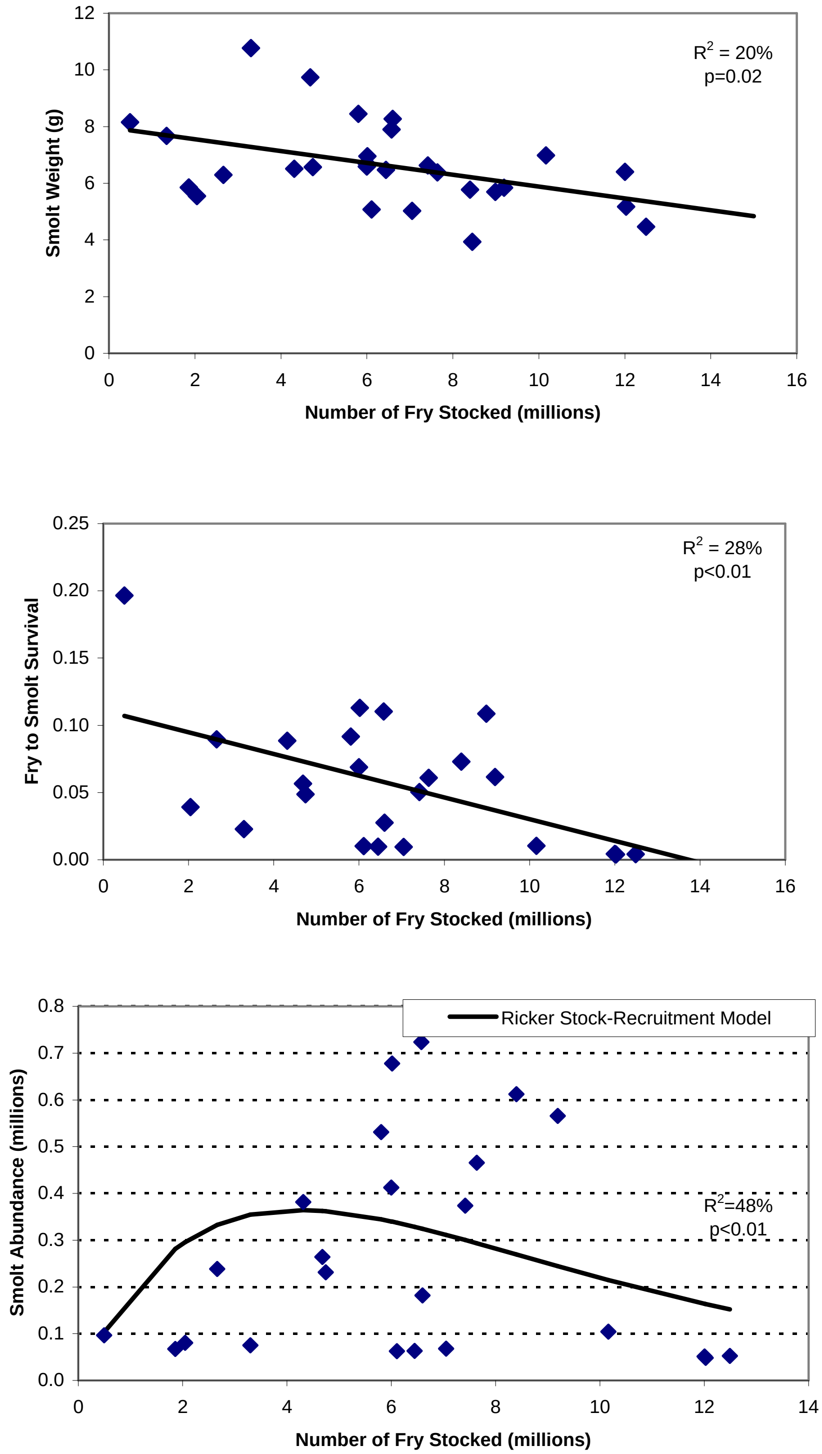


Figure 10. Smolt weight (a), fry-to-smolt survival (b), and abundance (c) versus Summit Lake stocking level.

Attachment 3. Fisheries Management Review

Based on the Check List Criteria several management concerns are identified. For example the Phase 3 Plan states "*The current level of enhanced salmon production returning to hatchery facilities has added to the complexity of managing the wild salmon mixed stock fishery. Consequently the Phase 3 Plan does not recommend significant increase in adult returns to these facilities. Rather, the plan points towards opportunities that may be provided in various remote release locations throughout Prince William Sound.*" The Phase 3 Plan recommendations suggest production increases be located at remote sites because of the complexity of managing wild salmon in mixed stock fisheries at current production levels. These PARs have no remote releases, nor was there any discussion about this subject at committee level. Instead, these PARs increase production at all hatchery facilities by more than 20%. This is counter to the Phase 3 Plan recommendation that increases be located at remote sites because of the added complexity of managing wild salmon mixed stock fisheries at current levels. Managing for wild stock escapement at current levels of production is difficult because of wild stock harvest and straying issues. Increased production at centralized hatchery locations may result in greater wild stock harvest rates, further complicating management for those stocks.

Pink Salmon

PWSAC is permitted to take up to 462 million green pink salmon eggs in PWS and is requesting a 22.3% increase to 565 million eggs.

The wild pink salmon sustainable escapement goal (SEG) range set by the department in 2002 is 1,250,000–2,750,000 fish for PWS. Consistent and large scale hatchery pink salmon production, mixed with highly variable and relatively small wild stock production, results in a broad differential in sustainable exploitation rates that is hard to predict and regulate. Since 2003, the maximum SEG has been exceeded twice (2003, 2005); in the remaining years, escapement has been below the midpoint SEG and was below the minimum SEG in 2008. Since 2003, in all years except 2009, wild pink salmon harvested in commercial common property fisheries conducted in PWS has exceeded wild stock escapement. Exploitation of wild pink salmon stocks was greater than 50% in six out of the last seven years. The lower exploitation rate in 2009 is a product of a small wild stock run coupled with a very conservative approach to the pink salmon fishery in terms of time and area. The risk of overharvesting wild pink salmon stocks in enhanced stock fisheries will increase with expanded hatchery pink salmon production.

Wally Noerenberg Hatchery (WNH)

PWSAC is permitted to take up to 148 million green pink salmon eggs for broodstock at WNH and is requesting a 27.0% increase to 188 million.

Wild pink salmon returning to the Coghill and Northwestern districts have similar run timing to enhanced pink salmon returning to WNH. Due to the mixing of wild and enhanced pink salmon, the harvest of wild pink salmon in the commercial fishery is a management concern. Commercial harvest of enhanced pink salmon returning to WNH generally begins in late July. Portions of the Coghill District are migration routes for salmon bound for Northwestern and Northern districts.

Additionally, wild salmon in the Esther Subdistrict may be headed for other districts, as well as streams within the Coghill District.

Harvest of wild salmon in the Coghill District may lead to shortfalls in escapement in other areas. In 2008, 368,000 wild pink salmon were harvested in limited portions of the Esther Subdistrict. This accounted for more than 65% of wild stock pink salmon harvested within Coghill District. Additionally, in 2008, Northwestern, Coghill, and Northern districts fell short of their management targets by approximately 70,000 salmon. In 2009, management of the enhanced pink salmon fishery was more conservative than 2008, with no fishing outside the Esther Subdistrict. During much of the pink salmon season the area was reduced within the subdistrict to provide corridors in an attempt to decrease wild stock harvest.

Increased WNH pink salmon production will exacerbate this issue. Fishing time will likely be less than the current 14-hour periods. Additionally, fishing periods will likely occur every other day or every third day rather than daily to allow escapement windows for wild stocks. Area restrictions similar to, or even more severe than those employed during the 2009 fishing season will likely become routine. With a growing fishing fleet, crowding and congestion will be common. Time and area restrictions may cause fish to build up more frequently in hatchery terminal areas, which may cause a decline in fish quality and increased possibility of straying.

An increase in the production of pink salmon at WNH also presents allocation issues. There is significant overlap in run timing between enhanced pink and coho salmon. Coho salmon, arriving in the fishery in large numbers by mid-August, are allocated to the drift gillnet fleet. According to 5AAC 24.370 *Prince William Sound Management and Salmon Allocation Plan*, purse seine gear may be operated in the Coghill District while the harvestable surplus is predominantly pink salmon. Increasing WNH pink salmon production may extend the time the seine fleet fishes in the Coghill District, allowing the harvest of a larger portion of the enhanced coho salmon run intended for the gillnet fleet.

Cannery Creek Hatchery (CCH)

PWSAC is currently permitted to take up to 152 million green pink salmon eggs at CCH and is requesting a 23.0% increase to 187 million. Historically, PWSAC has taken up to 161 million eggs (1989) and has been taking 152 million eggs (5-yr average 2005–2009) at this facility.

While this fishery largely avoids migration corridors, pink salmon stocks in Siwash and Jonah bays are directly affected. These stocks are relatively small in comparison to the hatchery return but make up approximately one third of the Northern District wild pink salmon stocks. Harvest of local stocks such as those in Siwash and Jonah Bays is controlled with time and area restrictions within Unakwik Inlet. Additionally, management is constrained in the CCH enhanced pink salmon fishery throughout the season because the CCH THA and SHA are often closed to ensure hatchery needs (i.e., cost recovery and broodstock) are met. Wild salmon were still harvested in larger numbers than intended, even though fishing was limited to the eastern half of the CCH Subdistrict in the last two years. Wild salmon made up less than 3% of the total CCH Subdistrict CPF harvests in 2008 and 2009, yet there were shortfalls in wild stock escapement.

Increased CCH pink salmon production will increase the risk of overharvesting local wild stocks. Fishing time will likely be less than the current 14-hour periods. Additionally, fishing periods will likely occur every other day or every third day rather than daily to allow escapement windows for wild stocks. Area restrictions similar to, or even more severe than those employed during the 2009 fishing season will likely become routine. With a growing fishing fleet, crowding and congestion will be common. Time and area restrictions may cause fish to build up more frequently in hatchery terminal areas, which may cause a decline in fish quality and increased possibility of straying.

Armin F. Koernig Hatchery (AFK)

PWSAC is currently permitted to take up to 162 million green pink salmon eggs at AFK and is requesting a 17.3% increase to 190 million.

The AFK hatchery is situated in one of the primary salmon migration corridors in PWS and harvest of wild pink salmon returning to all districts within PWS is a concern. At current levels of hatchery production, fishery managers struggle to limit wild salmon harvest in the Southwestern District. To adequately harvest AFK Hatchery enhanced pink salmon, while minimizing harvest of non-targeted salmon stocks, the fishery is often restricted to hatchery subdistricts or the THA in Sawmill Bay. In years with large hatchery returns, it has been necessary to move out of terminal areas for ‘clean ups’ of hatchery fish. As wild salmon become a smaller component of the fishery it will become more difficult to target large numbers of enhanced salmon while minimizing wild salmon harvest. The difficulty of minimizing wild stock harvest was demonstrated in 2009. Fishing area was restricted to the AFK hatchery THA and SHA for most of the season with limited openings in the Southwestern District to target enhanced salmon. Despite limiting area to reduce potential wild stock harvest, more than 500,000 wild pink salmon were caught in this primary migration corridor during a season when escapement indices in much of PWS were below desired levels. Increased hatchery production lowers the probability of moving beyond hatchery terminal areas to conduct targeted fisheries for enhanced salmon.

Increased AFK pink salmon production will increase the risk of overharvesting wild stock pink salmon of unknown origin in this mixed stock migration corridor. Fishing time will likely be less than the current 14-hour periods. Additionally, fishing periods will likely occur every other day or every third day rather than daily to allow escapement windows for wild stocks. Area restrictions similar to, or even more severe than those employed during the 2009 fishing season will likely become routine. With a growing fishing fleet, crowding and congestion will be common. Time and area restrictions may cause fish to build up more frequently in hatchery terminal areas, which may cause a decline in fish quality and increased possibility of straying.

Chum Salmon

PWSAC is permitted to take up to 148 million green eggs in PWS and is requesting a 21.4% increase to 165.4 million.

The wild chum salmon minimum SEG is 91,000 salmon in PWS and the department manages for the long-term average escapement in each district. Since 2003, the target escapement for chum salmon has been surpassed in all but two years, 2005 and 2009.

Armin F. Koernig Hatchery (AFK)

PWSAC is currently permitted to incubate up to 17.4 million green eggs at AFK and is requesting a 100% increase to 34.8 million. Historically, PWSAC has taken up to 17.4 million eggs (1989) and has been incubating and releasing progeny from 17.1 million eggs (3-yr average 2007–2009) at this facility.

The AFK hatchery is situated in one of the primary salmon migration corridors in PWS. Returning enhanced chum salmon share run timing with wild sockeye salmon bound for Coghill Lake and other systems in northern Prince William Sound, with wild chum salmon returning to systems in the Northern and Coghill districts, and with enhanced sockeye salmon returning to the Main Bay Hatchery (MBH). The fishery targeting enhanced chum salmon is conducted in the AFK SHA and THA in Sawmill Bay; fishing area and time are adjusted to limit interception of wild salmon and enhanced sockeye salmon returning to MBH. Despite using these management tools to limit harvest, there is still incidental take of non-targeted salmon in this fishery. Since 2005, 190,000 MBH and 27,000 wild sockeye salmon have been harvested in this fishery.

Management of this fishery is not likely to change with increased production. The fishery is generally open for 156 hours per week and is limited to the SHA and THA. Occasionally, area is increased within Sawmill Bay. This fishery produces frequent complaints of congestion and crowding of vessels. Increasing the chum salmon run by a factor of two may draw more participation from the purse seine fleet and further add to the congestion in the fishery.

An increase in chum salmon returns may escalate incidental harvest and allocation concerns. MBH sockeye are allocated to the drift and set gillnet fleets; thus, an increase in harvest of these fish by the purse seine fleet would result in diminished harvests by drift and set gillnet permit holders in the Eshamy District and potentially further exacerbate the current allocation imbalance.

<u>Sockeye Salmon</u>

Main Bay Hatchery

PWSAC is permitted to take up to 10.2 million green eggs at MBH and is requesting a 21.6% increase to 12.4 million.

Enhanced sockeye salmon returning to MBH share identical run timing with Coghill Lake stocks and similar timing with other smaller stocks in northern PWS. The location of the MBH at the terminus of Main Bay in the Eshamy District allows fishery managers to limit area in an attempt to control wild salmon stock harvest. Despite these management actions, 280,000 wild sockeye have been harvested in the Eshamy District since 2004. Similarly, permit holders in the Eshamy District frequently harvest significant numbers of returning wild stock salmon destined for other areas that migrate through the district. The fishery may be restricted to Main Bay Subdistrict to minimize harvest of non local wild stocks. This area reduction would likely occur more frequently with increased production levels.

Attachment 4. Hatchery Salmon Straying

Summary

Studies conducted by the department since 1997 have documented significant proportions of hatchery pink and chum salmon (up to 96%) within wild stock streams, including streams far from hatchery release locations. Department biologists are concerned about the impact of hatchery salmon on wild salmon stocks in PWS at current and proposed levels of hatchery production. The intermingling of hatchery and wild salmon could cause a host of harmful genetic and ecological impacts to wild salmon stocks that have been documented in the literature. Large numbers of hatchery salmon in streams also makes it prohibitively difficult to evaluate wild stock escapement throughout much of PWS. Given current levels of hatchery salmon straying, the department is unable to effectively manage for wild salmon escapement. Increases in hatchery pink and chum salmon production will further impair the department's ability to manage wild salmon stocks and increase the likelihood of harmful impacts to wild salmon stocks in PWS. Given available data collected on both pink and chum salmon straying to date, a precautionary approach would be to reduce hatchery pink and chum salmon production until a more thorough evaluation of the risks to existing wild stocks is complete. The department is currently entering the third year of a 3-year study of pink salmon straying and a study to examine possible gene flow from hatchery chum salmon strays into wild populations; therefore, these permit alteration requests are premature.

Overview of Hatchery Salmon Straying Impacts

Many studies and reviews have highlighted concerns about the deleterious impacts salmon enhancement programs can have on wild stocks of salmon (Araki et al. 2008; Naish et al. 2007; Myers et al. 2007; Mobrand et al. 2005; Aprahamian et al. 2003; Hilborn and Eggers 2001, 2000). Despite their wild origin, in only a few generations hatchery breeding, feeding, care, and release methods can result in domestication, alteration in gene frequencies, and phenotypic differences from their wild counterparts (Wang et al. 2002; Berejikian et al. 2001) that can be passed on to the progeny of hatchery-wild mating (Ford et al. 2006; Wessel et al. 2006; McClelland et al. 2005). As such, the breeding of captive or segregated stocks of salmon and subsequent hybridization of captive and wild salmon can result in a decrease in the fitness of wild salmon populations, even with relatively low rates of introgression (Ford 2002). Hatchery techniques can artificially shift the timing of spawning (Quinn et al. 2002), such that the progeny from hatchery-wild mating do not spawn at a time optimal for reproduction (Ford et al. 2006). Physical (competitive) interactions between hatchery and wild stocks of salmon may also have negative impacts to the wild stocks, regardless of whether interbreeding occurs. The stress and competition associated with crowding in streams can induce egg retention or mortality prior to spawning (Quinn et al. 2007) and also result in the destruction of redds (Quinn 2005).

Hilborn and Eggers (2000), noting a continued decline in wild pink salmon escapement in PWS, have suggested hatchery pink salmon are replacing, rather than supplementing, wild stocks in PWS. We believe that the straying of hatchery salmon into wild stock streams, and ensuing ecological and genetic interactions of wild and hatchery stocks, may be responsible for this replacement. The straying of hatchery fish into wild stock streams also inflates aerial survey estimates of wild stock escapement because, currently, all fish in streams are assumed to be wild. Therefore, without a comprehensive examination of hatchery salmon straying into wild stock streams, the department does not have the ability to accurately assess if established sustainable escapement goals (SEG) are being met. Given the weight of literature documenting the impacts of hatchery fish on wild stocks, the question is not whether hatchery releases will impact wild stocks, but whether the risks of the current and proposed releases are too large or whether they can be mitigated through management (Naish et al. 2008).

Definitions

Stray

The department and hatchery operators in Alaska have been developing an updated set of definitions related to genetics issues associated with anadromous Pacific salmon in Alaska. The definition of straying used for the studies conducted by the department to date is as follows: **a straying fish (stray) is a fish that dies in a non-natal spawning habitat.** A problem arises in attempting to determine whether the fish contributed to gene flow or not. The draft relationships of the hierarchy of definitions are shown in Figure 1.

Sustainable Escapement Goal (SEG)

As outlined in the *Policy for Management of Sustainable Salmon Fisheries* (5 AAC 39.223 (36)), "**sustainable escapement goal**" (SEG) means a level of escapement indicated by an index or escapement estimate that is known to provide for sustained yield over a 5 to 10 year period…"

Hatchery Salmon Straying Threshold and Assessment Projects in Prince William Sound

The department finfish genetics policy states, "Gene flow from hatchery fish straying and intermingling with wild stocks may have significant detrimental effects on wild stocks. First priority will be given to protection of wild stocks from possible harmful interactions with introduced stocks." (Davis 1985). Towards this end, the department, in cooperation with PWSAC, created the *Prince William Sound/Copper River Comprehensive Salmon Plans (Phases 1, 2, and 3)*. This plan stresses protection of wild stocks in management and hatchery practices. In 1994, the Prince William Sound/Copper River Regional Planning Team (RPT) finalized the *Prince William Sound/Copper River Phase 3 Comprehensive Salmon Plan*. Within the plan, the need to determine and monitor the rate of hatchery salmon straying into wild stock streams is clearly outlined. In particular, section 4.30 of the plan titled, "Maintain Straying Rates Below Threshold" states:

> "Straying of hatchery-reared salmon into wild-stock streams may reduce wild-stock productivity, because genetic variability among wild stocks is reduced. Since the late 1980's, hatchery salmon have greatly outnumbered wild salmon in PWS. Under these conditions, even relatively low straying rates of enhanced stocks may cause reduced genetic variability among affected wild stocks, because the straying rate as a proportion of wild-stock escapement is relatively high. At the present time, the straying rate of hatchery salmon in wild-stock streams is not known. A monitoring program should be implemented to periodically estimate the rate of hatchery-salmon straying into wild-stock streams, and to better define genetic stock boundaries in PWS. If it is determined that the rate of straying is significantly greater than the acceptable threshold of 2%, the PWS/CR RPT will determine whether and to what extent the hatchery program in PWS should be modified to reduce the rate of straying. The PWS/CR RPT recognizes that the present estimate of the acceptable threshold of hatchery-salmon straying is not well supported. Further research is needed to improve our confidence in the estimate of acceptable hatchery-salmon straying rates. This work must include studies to determine the effect of interbreeding of wild and hatchery salmon on the productivity of wild salmon. Hatchery operational strategies that may minimize straying or the effect of hatchery-salmon straying should also be examined."

The *Phase 3 Plan* (1994) specifies an "acceptable threshold of 2%." However, there were few estimates of hatchery straying rates and little literature support for the 2% threshold. Ford (2002) documents results from a quantitative genetics model indicating that 1) if the hatchery stock(s) are segregated from the wild stock(s), 2) if there is any selection in captivity (intentional or inadvertent), and 3) if there is gene flow from hatchery stock(s) into wild stock(s), then over a wide range of model parameter values, phenotype shifts can occur that lead to a >30% loss of fitness. If the three criteria above are met, the model also indicated a significant (knife edge) drop in fitness if the hatchery origin proportion in wild streams exceeds 10%. Mobrand et al. (2005) used the Ford (2002) paper results and suggested a precautionary threshold of 5% or fewer hatchery strays.

PWS Pink Salmon

Two kinds of hatchery practices produce different genetic outcomes. In a segregated hatchery system in which eggs are taken from only hatchery fish, the hatchery population is closed to gene flow from wild populations. As a result the hatchery population can diverge genetically from wild populations. Straying of fish from these kinds of hatcheries into wild populations can potentially have a large genetic impact because of the genetic differences between the hatchery and wild populations. Another hatchery practice is to periodically introduce wild fish into a hatchery population. This has the effect of keeping hatchery and wild populations genetically similar and reduces the genetic impact that hatchery strays might have on wild populations. Ford (2002) described the worst-case scenario as a hatchery stock closed to gene flow from wild stocks and wild stocks that are subject to continual gene flow from hatchery stocks.

The existing data indicate these hatchery broodstocks are essentially closed to gene flow from wild stocks (segregated stocks). In 1997–1999, the department examined pink salmon hatchery broodstocks at Solomon Gulch, Cannery Creek, and Wally Noerenberg hatcheries, and in 1998 and 1999 at Armin F. Koernig Hatchery. The highest proportion of wild fish documented was 1.2% and 6 of the 11 hatchery-year samples contained no unmarked fish. PWSAC examined pink salmon broodstocks again in 2008 and documented 100% hatchery fish in the broodstocks at Cannery Creek and Wally Noerenberg hatcheries and >99.0% hatchery fish at the Armin F. Koernig Hatchery (Smoker 2009; Final Contract Report). The existing data indicate these hatchery broodstocks are essentially closed to gene flow from wild stocks (segregated stocks).

Thermal marking of otoliths in hatchery fish has been useful for measuring proportions of hatchery origin fish that stray into natural streams. From 1997–2006, hatcheries in PWS released an average of 585 million pink salmon fry with thermal marked otoliths. These marks have provided precise estimates of total run and marine survival. The range of marine survivals (3%–9%) and a specified release size were used to calculate the number of returning adults that could stray before they would exceed a specified percentage of the wild pink salmon sustainable escapement goal midpoint (2 million).

The PWS pink salmon SEG is an index, and does not account for observer efficiency and the proportion of the total escapement represented by SEG streams. Therefore, the SEG was expanded to account for observer efficiency and the proportion of surveyed versus non-surveyed streams (Fried et al. 1998). The percentage of an adult return that could stray before exceeding suggested threshold percentages of hatchery strays was then calculated at the following thresholds: 1) 2% (CR/PWS phase 3 plan 1994), 2) 5% (Mobrand et al. 2005), and 3) 10% (Ford 2002). At the average release size of 585 million fry and a marine survival of only 3%, a maximum of 3.26 % of the adult return could stray before they would exceed 10% of our expanded SEG midpoint (Figure 2). At the proposed total PWS release of ˜722 million pink salmon fry (PWSAC and Valdez Fisheries Development Association combined), the maximum percentages of returning adults that could stray before exceeding 10% of our expanded SEG midpoint would be 2.64% at a 3% marine survival, but only 0.88% at a marine survival of 9%. These calculations can be used for planning and clearly indicate that current levels of hatchery releases are so large that there is little chance the number of strays is below the 10% level in most years.

Several department studies show considerable straying of hatchery fish over long distances from the original release site. The department conducted a 3-year (1997–1999) examination of pink salmon straying in PWS coinciding with the first returns of thermal marked otoliths in 1997 (Joyce and Evans, 1999). For pink salmon, 14 wild stock streams, each sampled 3 times during 1997, contained 26%–96% hatchery fish. Additionally, some streams located >35 km from hatchery release sites contained over 50% hatchery pink salmon. Hatchery salmon straying proportions in 1998 and 1999 ranged from 0% to 96% within individual streams (unpublished work by Joyce and Evans; Table 1). Additional evidence of straying of PWS hatchery pink salmon at much larger distances (>900 km) from the original release site were documented by otolith thermal mark recoveries of PWS fish in Southeast Alaska streams in 1999 and 2000 (Agler et al. 2001).

The department began its second 3-year examination of hatchery pink salmon straying in 2008 (funded by Pacific Coastal Salmon Recovery Fund (PCSRF)) with the intention of estimating the spatial and temporal extent of hatchery pink salmon straying throughout PWS. This study is currently funded through 2010 and a proposal has been submitted to extend funding through 2011. In this study, 30 of the largest pink salmon spawning locations were randomly selected and carcasses were sampled multiple times in each stream. Pink salmon carcasses were also sampled in streams that were part of other long-term research projects. For 2008, sampled streams contained 0%–79% hatchery pink salmon with an unweighted average of ≈12% hatchery pink salmon per stream. In 2009, sampled streams contained 0%–84% hatchery pink salmon with an unweighted average of ≈18% per stream. Most concerning to department biologists is the finding of high proportions of hatchery salmon in historically significant wild stock streams that are not immediately adjacent to hatcheries. Similar to the Joyce and Evans study, proportions of hatchery pink salmon in excess of 50% have been documented in wild stock streams more than 35 km from the nearest hatchery release site.

Using data from our straying studies, we developed and parameterized a preliminary model designed to extrapolate hatchery pink salmon straying proportions throughout PWS. The initial model was parameterized using release numbers from just two hatcheries (Wally Noerenberg and Armin F. Koernig hatcheries). The model predicts that hatchery pink salmon straying proportions in wild stock streams are expected to be >10% for large areas of PWS. With additional years of data we will refine our model to include a temporal component and other hatchery release locations. We anticipate that a spatio-temporal model will enable us to better understand how various hatchery and management practices, such as timing and length of commercial fishing periods (effort), and number and timing of hatchery fish releases and returns, affect straying across seasons and years.

Chum Salmon

As described earlier for pink salmon, Ford (2002) described the worst-case scenario as a hatchery stock closed to gene flow from wild stocks, and wild stocks that are subject to continual gene flow from hatchery stocks. Results from an examination of chum salmon broodstock at Wally Noerenberg Hatchery in 2008 suggest the chum salmon stock is essentially segregated from wild stock gene flow. The final contract report of the work funded by PWSAC (Smoker 2009) indicates that only 1.1% of a sample of 2,915 readable otoliths examined for thermal marks were unmarked fish.

The department is currently conducting large-scale projects to quantify straying of hatchery pink and chum salmon in streams throughout PWS. As part of the PCSRF study, gene frequencies in samples of unmarked spawning fish collected in 2008–2010 will be compared to gene frequencies in pre-hatchery scale collections from the same streams. Significantly different gene frequencies would indicate that gene flow from hatcheries into wild populations has not been important. Genetic similarity between hatchery and wild populations could provide evidence of hybridizations between hatchery and wild fish.

The department initially became concerned about hatchery chum salmon straying in 2002 and 2003 when unusually large numbers of chum salmon appeared at the Eshamy River weir. The majority of chum salmon sampled for otoliths at the Eshamy River weir were of hatchery origin (2002 = 92% and 2003 = 87%). As a result, a pilot study was initiated in 2004 to more closely examine hatchery chum salmon straying in PWS. In 2004, sampled chum salmon carcasses in 10 of 14 (71%) streams contained more than 2% hatchery strays based on otolith thermal marks. In 2005, 12 of 17 (71%) selected streams had greater than 2% hatchery chum salmon strays.

In this study, we investigated hatchery chum salmon straying at historically significant (average escapement indices > 1,000) chum salmon spawning locations. (Merizon and Moffitt, *in press*; Brenner and Moffitt, unpublished). Results document individual wild stock streams with between 0% and 63% hatchery chum salmon (Table 1). Additional evidence for hatchery chum salmon straying comes from aerial surveys that show a large increase in chum salmon escapement (from 5,000 to 120,000) in the Southwestern and Montague districts following release of hatchery chum salmon in 1994 (Figure 3). Some level of straying of hatchery chum salmon into streams in the Port Chalmers area of the Montague District had been expected when the releases were permitted. However, to date, fish carcasses with otolith marks that were intended for release at Port Chalmers have been collected >60 km from the release site each year (2004–2009).

Department staff created a model to examine the relationship between the proportion of pink salmon hatchery strays in a stream and the distance from the release site. The department considered the same model for hatchery chum salmon; however, an examination by PWSAC indicated marked fish were likely not released in the intended locations for several years. Therefore, a model incorporating the relationship between proportion of hatchery fish at a location and the distance from release site would not be valid because the release sites of individual marks are uncertain.

Instead, department staff created a Monte Carlo simulation model to estimate the weighted percentage of hatchery fish in the total escapement. This model used data for 2004–2007 and considered uncertainty in estimates of hatchery-run age composition and estimated proportion of hatchery fish in sampled streams to generate a frequency distribution of estimates at a given hatchery release size (Figure 4). Estimates of the probability that releases would exceed the 2%, 5%, or 10% levels of total escapement were estimated for releases of 76 million and 146 million.

This model and results were presented at the 2007 Alaska American Fisheries Society meeting in Ketchikan and to the PWSAC Executive Committee on 10 December 2007. Given a release size of 146 million chum salmon (the largest release 1997–2006), the model predicts a probability of 0.10 that hatchery strays would exceed 10% of total PWS chum salmon escapement. Additionally, the model predicts there is no chance hatchery strays would account for less than 2% or 5% of total PWS chum salmon escapement (Figure 4). The model predicts that the smallest release size in recent years (76 million) would have a probability of 0.22 that strays would exceed 5% of total PWS chum salmon escapement. The current model does not account for uncertainty in hatchery contributions to commercial harvests or uncertainty in estimates of escapement. Therefore, the model predictions of frequency distribution would likely be more dispersed if all uncertainty were considered, i.e., the model currently underestimates the uncertainty.

Sockeye Salmon

Sockeye salmon otoliths have been collected from carcasses during pink and chum salmon straying sample trips, and from live and dead fish as part of the monitoring of escapement at weirs on the Coghill and Eshamy rivers.. From 2004 through 2009, samples from carcasses collected at streams without documented sustainable sockeye salmon populations have been mostly strays from Main Bay Hatchery (26 of 37). This included fish in a stream that was located more than 80 km from Main Bay Hatchery, Marsha Bay, or Solf Lake.

Strays into Eshamy Lake are of significant concern to the department because the existing Main Bay Hatchery stock is mostly Coghill Lake fish; the Eshamy and Coghill lake stocks have significantly different run timing and age compositions indicating that hybrids of the two would be unlikely to be successful. The weighted average percentage (2006-2009) of Main Bay Hatchery fish sampled at the Eshamy River weir is 6.2% with a range of 0.7% to 22.3% (n =1,231). Most samples have been from live fish; however, the highest percentage (22.3%) in 2007 was from mostly dead fish samples (192 of 288). Hatchery proportions were >6% in all three sampling events in 2007 (7/29, 8/16, and 8/25). Straying into Eshamy was <2% for years 2006, 2008, and 2009.

Straying Effects on Escapement Goals

In addition to separating harvests of wild and hatchery stocks (Attachment 3), increases in production would probably also increase levels of straying and exacerbate the ability of the department to measure escapement. The department manages for wild salmon escapement goals based on aerial survey indices of fish in streams. Because it is not possible to differentiate between wild and hatchery salmon during aerial surveys, all salmon counted in streams have been assumed to be of wild origin. Therefore, presence of stray hatchery fish in index streams inflates wild stock escapement estimates and can mask a decline in wild stock escapements. Department biologists are in the process of reconstructing past escapements to revaluate existing wild stock escapement goals given the measured numbers of hatchery strays. Such a reconstruction requires a significant modeling and statistical effort and is ongoing.

Because hatchery strays cannot be identified during inseason aerial surveys, the decision to open commercial fishing may occur before a sufficient number of wild fish have escaped to spawn. In 2009, otoliths from salmon carcasses sampled in streams contained an unweighted average of ≈18% hatchery pink salmon strays and ˜ 14% hatchery chum salmon strays. Therefore, it is clear that stray hatchery salmon are inflating wild stock escapement estimates and influencing management decisions to the detriment of wild stocks

Straying and Allocation Issues

Straying of hatchery salmon may also impact the *Prince William Sound Management and Salmon Enhancement Allocation Plan* (5 AAC 24.370). Hatchery pink and chum salmon may be harvested by unintended gear groups or in unintended locations, which may influence gear-specific exvessel values. For example, as part of the PWS Allocation Plan in 2003, Port Chalmers remote release chum salmon were intended for harvest by the purse seine fleet in the Montague District. However, more than 300,000 chum salmon destined for Port Chalmers were harvested in the Coghill District harvest in 2003, with at least 130,000 of these fish harvested by the gillnet fleet in the Coghill District. While the 2003 run had the largest number of fish harvested by an unintended gear group, this has been an issue in other years as well (e.g., Ashe et al. 2005).

Straying and Cost Recovery

Straying of hatchery fish has implications for cost recovery and broodstock collection. In years when few hatchery salmon return, hatchery strays may exacerbate a run shortfall and could ultimately lead to a hatchery corporation's inability to achieve cost recovery or broodstock collection goals. Straying fish do not return to hatchery terminal areas and therefore, are not available for cost recovery or broodstock collection.

CONCLUSIONS

Analysis of hatchery-marked fish in wild streams and models of straying indicate that considerable straying of hatchery fish into wild populations for pink and chum salmon is occurring. Hatchery populations in PWS are generally treated as closed systems with little use of wild fish in hatchery broodstocks and this can lead to genetic divergence of hatchery populations from wild populations. The high level of straying into many streams is of concern, because of the potential for hybridization between wild fish and hatchery fish, which may come from populations that are genetically divergent from wild populations.

Even without gene flow from hatchery strays into wild populations, large numbers of stray hatchery fish may affect wild fish ecologically by competing for limited spawning space and digging up spawning redds. Stray hatchery fish also confound estimation of wild stock escapements and therefore, inseason fishery management decisions. This affects the department's ability to meet its statutory and regulatory requirements to manage for sustained yield of wild salmon as the highest priority.

Tables and Figures

Table 1. The average annual proportions of hatchery pink and chum salmon within wild-stock streams in Prince William Sound. Hatchery salmon were identified by thermally marked otoliths. All salmon died naturally prior to sampling. Sampled streams were distributed throughout the sound except as footnoted otherwise.

Pink Salmon

	YEAR				
	1997[a]	**1998**	**1999[b]**	**2008**	**2009**
Average Stream Straying Proportion	62%	20%	9%	12%	18%
Range	25-96%	0-96%	0-30%	0-79%	0-84%
# of Streams Sampled	14	25	33	34	37

Chum Salmon

	YEAR					
	2004	**2005**	**2006**	**2007**	**2008**	**2009**
Average Stream Straying Proportion	9%	9%	3%	18%	2%	14%
Range	0-36%	0-63%	0-9%	0-100%	0-11%	0-45%
# of Streams Sampled	11	14	11	26	15	16

[a] Most streams sampled from the SW District of PWS.
[b] Most streams sampled from northern and eastern PWS.

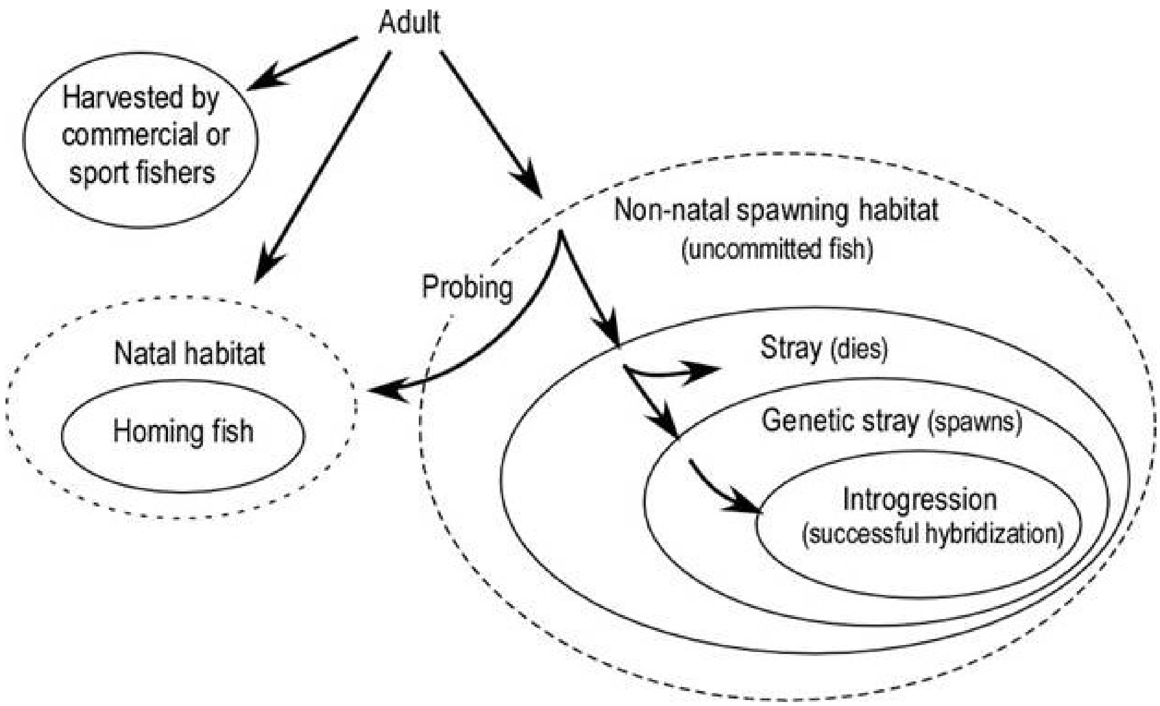


Figure 1. Draft diagram of the hierarchical relationships among adult fish (from draft version provided by ADF&G Genetics Conservation Laboratory staff).

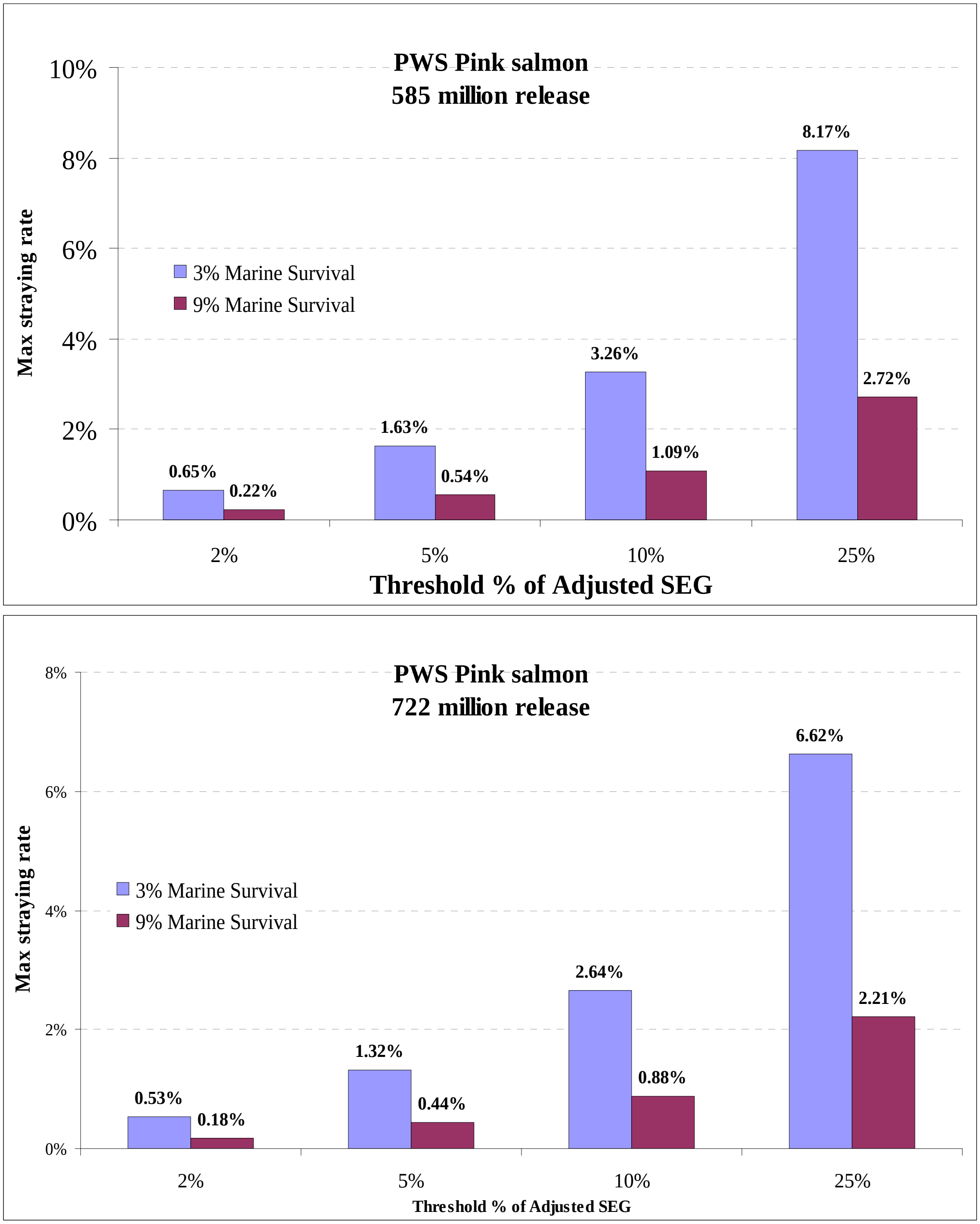


Figure 2. The maximum straying rate of hatchery pink salmon at releases of 585 million (1997–2006 PWS average; top panel) and 722 million (proposed beginning in 2011; bottom panel) before strays would exceed threshold percentage levels of the adjusted SEG midpoint. The maximum straying rate is shown at the range of marine survivals estimated from 1997–2006 (3% and 9%). Straying thresholds used are 1) 2% (PWS/CR Phase 3 plan), 2) 5% (Mobrand et al. 2005), 3) 10% (Ford 2002), and 4) 25% (shown for comparison purposes). Marine survival estimates are biased low because stray hatchery fish in stream escapements were not estimated and included.

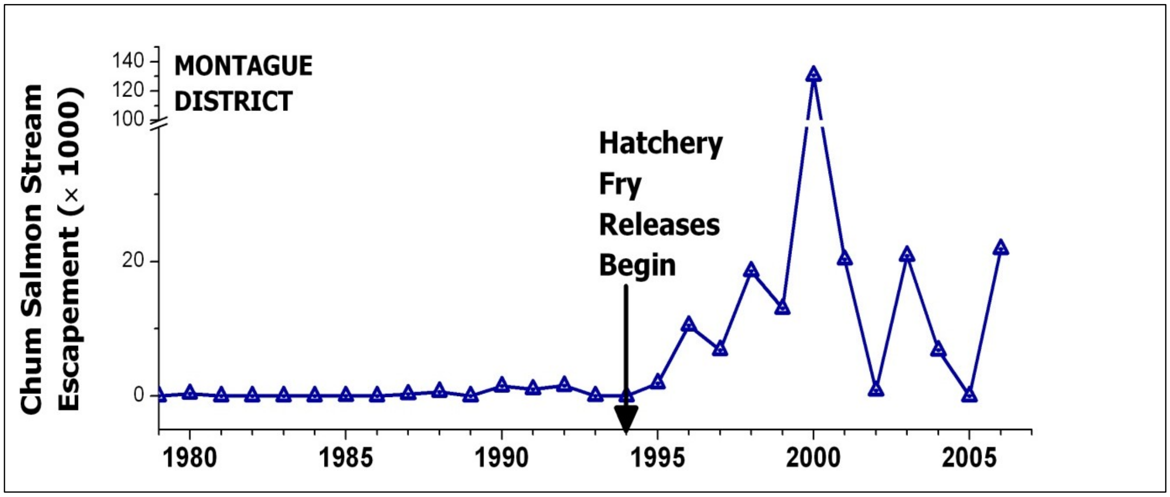


Figure 3. Total aerial escapement index of chum salmon into Montague District streams, 1979–2006.

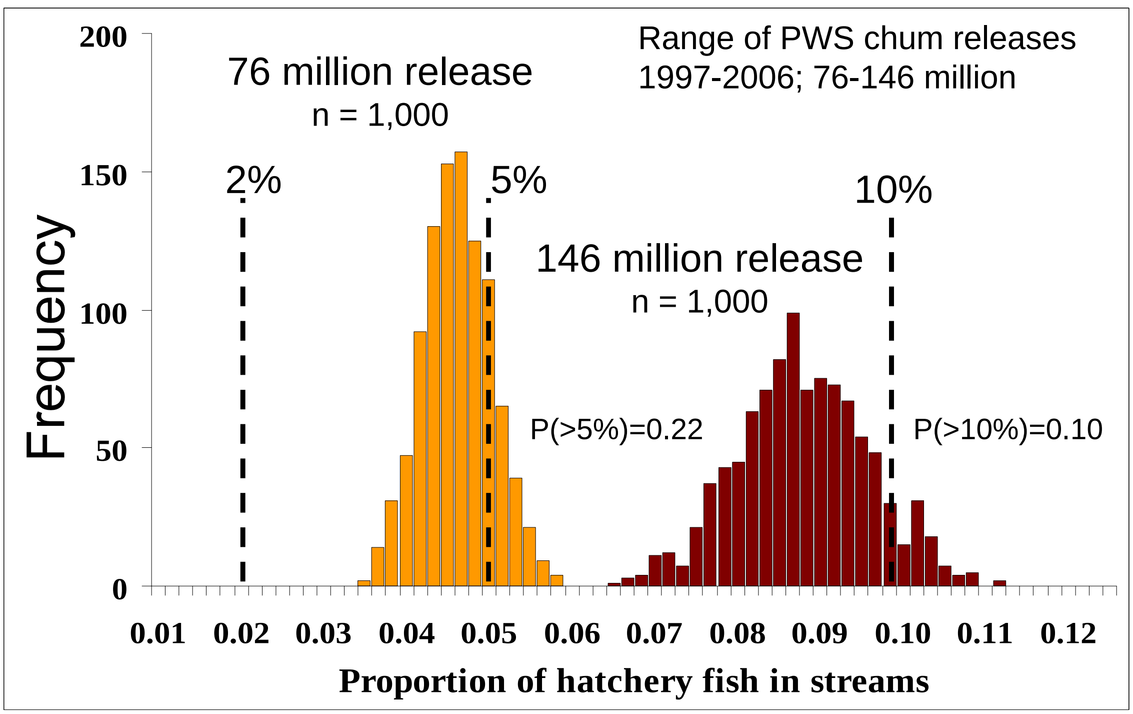


Figure 4. Frequency distribution of the proportion of weighted average of hatchery fish in PWS streams at the range of chum salmon release sizes between 1997 and 2006 (76 million to 146 million). These results are from a Monte Carlo simulation model.

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Attachment 5. Genetics

The department interprets its mandate for managing salmon populations under the sustained yield principle to mean that wild populations should be protected, and the conservation of within- and between-population genetic diversity is an important part of this conservation effort. In recognition of the importance of genetic diversity, the ADF&G finfish genetics policy states, "*Gene flow from hatchery fish straying and intermingling with wild stocks may have significant detrimental effects on wild stocks. First priority will be given to protection of wild stocks from possible harmful interactions with introduced stocks*."

Straying of hatchery fish into wild populations potentially affects the genetics of wild populations in three ways. First, persistent straying of hatchery fish and hybridization with wild fish can lead to loss of between-population genetic diversity (Waples 1991). Conserving the geographic component of genetic diversity is important because wild populations are adapted to a wide range of habitats. This source of genetic diversity is important for adapting to climate shifts and hence, for long-term persistence. Second, within-population genetic diversity is needed to enhance the probability of persistence of local populations. Wild populations that are reduced in size by competition from hatchery strays may lose genetic diversity because of random drift. Inbreeding in these populations can lead to adverse effects on individual fitness and population persistence (Lynch and Lande 1998; Frankham 2005). Third, hybridization between genetically divergent strays and wild fish can reduce fitness of hybrid offspring (Ford 2002; Araki *et al.* 2007). Of these three concerns, concern #1 and #3 are most applicable to populations of pink, chum, and sockeye salmon in PWS.

Hatchery practices in PWS have led to segregated hatchery populations, which receive little gene flow from wild populations (Attachment 4, Hatchery Salmon Straying). As a result, hatchery populations are prone to diverge from wild populations (e.g., Kostow 2004). This divergence can occur rapidly in a few generations and is usually attributed to survival and domestication under hatchery conditions (Araki *et al*. 2007; Fritts *et al.* 2007). Hybridizations between hatchery and wild salmon can influence genetically based life-history characteristics of the 'wild' population. For example, long-term hybridizations between early-run hatchery and late-run coho salmon led to earlier run timings of the 'wild' population (Ford *et al*. 2006). Hence, hybridizations between hatchery strays and wild populations in PWS are expected to have significant effects on the genetic integrity of wild populations.

The very large production of salmon in hatcheries and the large amount of straying that has been documented (Attachment 4) places wild populations in PWS at considerable genetic risk. Increases in hatchery-produced fish, as requested by the hatcheries, would put wild populations at increased risk by increasing hatchery salmon straying into wild salmon populations. Hence, the department's Genetics Section recommends caution in granting PWSAC's PARs to increase production of pink, chum, and sockeye salmon. A cautionary approach is needed until more detailed information on the extent of hybridization between hatchery and wild fish becomes available. This approach mandates no increases in the present levels of production until the department develops a clear plan to address hatchery salmon straying.

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Attachment 6. Allocation

Each PAR presents production increases as moving a step closer to achieving Phase 3 Plan production goals. These goals are identified and discussed in Attachment (1) of the PAR package and it states

> "*Our knowledge limitations predicate production increases be described at present by an upper limit. The upper limit of production is based on our current understanding of biological aspects of salmon culture, fisheries management, and achieving maximum sustained yield of wild stocks. The limit is also based on existing hatchery water supplies, limits of economical feasible production, production and release opportunities to reduce fleet congestion, and projected allocation parity between user groups. The upper limit is an attainable goal if all conditions are met.*"

The department is neutral regarding allocation of the resource. However, since we are charged with trying to manage fisheries to meet allocations made by the Board of Fisheries, it is appropriate to assess how the proposed PARs may affect those allocations. Increasing hatchery production satisfies some allocation plan objectives including: promoting highest possible fish quality and maximizing production. However, production increases may be contrary to other objectives. The PARs will likely increase congestion in the fishery as increasing hatchery fish returns and an increasing trend in active permits, combined with wild stock harvest concerns, will result in many boats fishing in small terminal areas. The PARs will likely increase conflict in the fishery as the allocation imbalance continues into the future. Instead of minimizing impact to wild stocks, these PARs have the potential to increase the impacts to wild stocks. These PARs may increase harvest of wild stocks as the number of hatchery fish and effort to harvest them increase. Wild stock harvest rates are already of concern at current production levels. Additionally, increased production and associated congestion create pressure for more fishing area, further increasing potential harvest. The PARs also impact historic and traditional fisheries. For example, implementation of these PARs is likely to perpetuate the current allocation imbalance, and traditional Port Chalmers seine fisheries will continue to be allocated to gillnet fisheries for the foreseeable future.

The importance of long term planning and production to achieve a balance in harvest opportunity and value between the commercial gear groups is identified in Alaska Board of Fisheries findings, the Phase 3 Plan, and PWSAC's Allocation Policy. PWSAC's allocation policy states "*It is the policy of PWSAC to equitably allocate enhanced salmon resources in Area E among all users through long-term planning, production and dedication of financial and human resource*" (Phase 3 Plan p.74). If approved, the PARs would extend and increase the current allocation imbalance between purse seine and drift gillnet permit holders. The current PWS catch by gear type is 62% seine and 38% drift gillnet. PWSAC projects that this set of PARs will annually add $6.2 million to the value of the seine fishery, while adding $2.2 to the value of the gillnet fishery. This would exacerbate the current allocation disparity. Until recently, allocation was the source of long-term and highly charged conflict between gear groups. The current allocation plan will likely be inadequate to balance the disparity, if these production increases are approved. These PARs are counter to these directives to use long term planning and production to achieve a balanced allocation. If approved in their entirety, these PARs will likely make the current allocation plan unworkable.

Attachment 7. *Density Dependent Survival and Growth*

Many studies have concluded there is inter and intra-specific competition for pink and chum salmon food resources in nearshore and offshore waters of the North Pacific Ocean. This competition has been linked to a substantial decrease in the productivity and body size of PWS wild pink salmon stocks. Perhaps most troubling is the deleterious impacts that pink salmon can have on high-value salmon species such as sockeye, coho, and Chinook salmon. One study calculated that there was a cumulative loss of 92 million sockeye salmon to Bristol Bay from 1977 to 1997 as a result of competitive interactions with odd-year pink salmon in the marine environment. Multiple studies have also connected the crash and lack of recovery of PWS herring to the large increase in hatchery pink salmon production in PWS. Proposed increases in production of hatchery salmon in PWS cannot be viewed in isolation. Rather, a large suite of ecological and economic tradeoffs must be considered, with a growing body of evidence suggesting hatchery salmon could come at a substantial cost to other fisheries and to wild salmon stocks. Hence, given the department's statutory and regulatory obligation to protect wild salmon stocks, department staff does not recommend increases in PWS hatchery pink and chum salmon production. The following is a summary of various studies that have examined competitive interactions between salmon (or between salmon and herring) in Alaska.

First, it is important that issues of density dependence and carrying capacity be considered within the context of a broad set of behavioral traits and ecological conditions which govern the feeding, movement, and migration of salmon and their prey. Interactions of behavior and ecological conditions for predators and prey cause spatial and temporal separation that limits access to food resources and is the basis of foraging arena theory. As explained by Walters and Martell (2004):

> "The basic idea of this theory is that most organisms exhibit spatial and habitat-choice behaviors aimed at moderating their predation risk, and this behavior in turn limits access to prey resources. Trophic interactions then take place mainly in spatially and temporally restricted "foraging arenas," where the competition for food resources can be intense but where only small proportions of the total food population may be at risk to predation at any moment. Further, these arenas of feeding activity generally expose feeding animals to predation risks, so that the processes of eating and of being eaten are closely linked."

A criticism against carrying capacity constraints induced by hatchery salmon programs is that only a fraction of available prey items are consumed by hatchery salmon. Within PWS, the study of Cooney (1993) has been erroneously cited as evidence that carrying capacity in PWS has not been reached for juvenile pink salmon. However, considering the studies summarized below that document size-selective mortality of pink salmon from PWS, a high degree of variability in yearly survival of pink salmon, competitive interactions of pink salmon within PWS and the department's own research showing spatial and temporal patterns of juvenile pink salmon movement within PWS, it is apparent that total zooplankton biomass for the entire PWS does not adequately explain salmon carrying capacity. Instead, density dependent and carrying capacity constraints on hatchery pink and chum salmon production within PWS must be considered within the contemporary view of the foraging arena, whereby behavioral, energetic and ecological tradeoffs dictate that only a fraction of overall prey resources (zooplankton) is actually available to juvenile salmon. While a comprehensive model that accounts for foraging arenas of juvenile and adult salmon has not been completed for PWS, the studies outlined below provide abundant evidence that a precautionary approach to salmon management precludes additional hatchery pink and chum salmon production in this region.

The proposed increase in hatchery pink and chum production for PARs submitted in 2010 will increase forage consumption in the coastal and oceanic zones of the North Pacific. As outlined by Cooney and Brodeur (1998), increase in fry production may increase competition for available forage and result in density-dependent growth in some populations. Fecundity and egg size are often directly related to body size. Smaller eggs generally produce smaller fry with a lower probability of survival. Therefore, increased production may lead to reduced body size and survival of both wild and hatchery stocks. This would potentially have a larger effect on wild fish because hatcheries could continue to produce fry with a smaller brood requirement even during periods of reduced coastal and oceanic productivity. Within their manuscript, Cooney and Brodeur (1998) state:

> "…our estimates of consumption suggest to us that recent high levels of wild and hatchery production in the North Pacific Ocean have probably placed substantial forage demands on both coastal and oceanic feeding domains. Under these conditions, it would seem surprising if density-dependent growth limitations were not evident in some populations."

> "For wild salmon, decreased body size and reproductive potential resulting from forage deprivation (increased competition or decreased ocean production) may serve as an important feedback mechanism to regulate population abundance under conditions of declining marine food reserves, but because hatchery production relies on much lower brood-stock abundances, ocean-ranching programs can continue to produce juveniles at high rates even during periods of diminished wild stock production. This ability could further exacerbate reproductive difficulties for wild populations by increasing competition for resources under more tightly constrained coastal and oceanic feeding conditions."

> "It seems apparent to us that productivity at lower trophic levels varies in response to yet-to-be-defined physical and meteorological factors in the North Pacific Ocean and that oceanic nekton respond accordingly (Brodeur and Ware, 1994). Although enhancement of salmon populations was designed to remove the influences of much of this variability, the strategy may have to be revisited and adjustments made to accommodate the limitations placed on all consumers by the apparent fluctuating nature of the carrying capacity of the ecosystem. To ignore the signals manifested in the diminished size of Pacific salmon is to invite potential disaster for these and other resources."

Based on a diet analysis of juvenile hatchery and wild pink salmon from PWS and the Gulf of Alaska, Armstrong et al. (2008) concluded that:

> "The lack of significant differences in diets and gut fullness between hatchery and wild juvenile pink salmon either in PWS or on the Seward Line indicated that PWS hatchery fish could compete with wild fish for the available food."

Werthheimer et al. (2004) examined body size and run size of pink salmon in PWS for years 1975–1999. They found the average body size of pink salmon had declined substantially during this period and attributed this decline to the overall density of pink salmon within the marine environment. They also calculated that hatchery pink salmon production in PWS had caused a substantial decline in yield of wild pink salmon:

> “For the 1975–1999 brood years, we found that an index of total abundance of pink salmon in the Gulf of Alaska and sea surface temperature during the year of return best explained the variation in pink salmon body size over time.”
>
> “Based on these linkages between hatchery production, body size, and wild-stock productivity, we estimated that decreased adult body size due to hatchery production reduced yield of wild fish in PWS at 1.03 million fish annually, with a 95% confidence interval of 0.21 to 2.7 million, for brood years 1990–1999.”

Their estimated decrease in wild pink salmon production of 0.2 to 2.7 million fish annually is a sizeable portion of the overall 1960–1975 pre-hatchery average wild run size in PWS of ˜6.8 million (S. Moffitt, unpublished). Although the authors compare their estimate of annual reduced yield to average annual hatchery return over the same years, a more informative comparison (given our wild stock priority mandate) would be to describe the loss as a proportion of our SEG midpoint goal for pink salmon. This loss in yield (0.2 to 2.7 million) would represent from 5% to 47% of our SEG midpoint index expanded to represent an estimate of fish. It is notable that their study did not account for the large number of hatchery pink salmon strays within PWS streams. If they had, their calculated loss of wild stock pink salmon would have been greater.

Cross et al. (2009) used scale patterns to investigate marine growth of pink salmon originating from PWS from 2001–2004. In addition to buttressing the idea that size-selective morality plays a significant role in determining overall population survival, the authors suggested that density-dependence might be regulating growth for pink salmon during some years:

> “The large influx of juvenile pink salmon into the Gulf of Alaska, in conjunction with the seasonal dynamics of zooplankton prey, could create localized prey depletions and density-dependent growth. Both the juvenile pink salmon population at-large and all cohorts that survived to adulthood grew at a faster rate from approximately mid–late June to mid–late August during the higher survival years of 2002 and 2004 than during the low survival years of 2001 and 2003. If density-dependent growth occurred, it might have been less intense during the summers of high-survival years than during low survival years.”
>
> “This study supports the findings of Beamish and Mahnken (2001) and Moss et al. (2005) that additional size-selective mortality occurs after the first growing season and significantly influences smolt-to-adult survival for pink salmon. The discrepancy in body size between the juvenile population at-large and those that survived to adulthood through circulus 15 suggests that significant size-selective mortality occurred after late summer. The probability of reaching a critical size in order to survive winter could be exacerbated by bottlenecks in prey supply.”

Moss et al. (2009) used data collected from numerous trawl surveys to construct a bioenergetics model. They used this model to compare growth and prey consumption for hatchery and wild pink salmon in the northern Gulf of Alaska. They concluded:

> “Significant differences in consumption demand and a two-fold difference in nearshore abundance during 2001 of hatchery and wild pink salmon confirmed the existence of strong and variable interannual competition and the importance of the nearshore region as being a potential competitive bottleneck.”
>
> “Our findings strongly suggest that there is intraspecific competition between hatchery and wild stocks during some years due to the spatial overlap of high densities in the nearshore region. The occurrences of smaller juvenile pink salmon when these conditions persist indicate density-dependent growth.”
>
> “Intraspecific competition for prey resources exists for hatchery and wild juvenile pink salmon stocks inhabiting the coastal Gulf of Alaska. The highest levels of intraspecific competition occurred nearshore, an area where interannual abundance of hatchery and wild pink salmon can vary by more than an order of magnitude.”

Ruggerone and Nielsen (2004) provided extensive documentation for competitive dominance of pink salmon over other species of salmon. According to their study, competitive dominance of pink salmon has resulted in decreased growth, survival, and run sizes for Chinook, chum, and sockeye salmon across broad geographic areas in the North Pacific Ocean. While a similar analysis has not taken place for salmon species in PWS and the Copper River, given the evidence for competitive interactions and large releases of hatchery pink salmon in PWS, it is quite plausible that hatchery pink salmon production are negatively impacting other salmon species in this area. Thus, the apparent short-term economic gains from hatchery pink salmon production in PWS should be weighed against the loss of other commercial, sport, subsistence, and personal use opportunities that might have occurred. Notable results from Ruggerone and Nielsen (2004) include:

> “Research consistently indicated that pink salmon significantly altered prey abundance of other salmon species (e.g., zooplankton, squid), leading to altered diet, reduced total prey consumption and growth, delayed maturation, and reduced survival, depending on species and locale. Reduced survival was observed in chum salmon (*O. keta*) and Chinook salmon (*O. tshawytscha*) originating from Puget Sound and in Bristol Bay sockeye salmon (*O. nerka*). Growth of pink salmon was not measurably affected by other salmon species, but their growth was sometimes inversely related to their own abundance. In all marine studies, pink salmon affected other species through exploitation of prey resources rather than interference. Interspecific competition was observed in nearshore and offshore waters of the North Pacific Ocean and Bering Sea, and one study documented competition between species originating from different continents.”
>
> “The consistent pattern of findings from multiple regions of the ocean provides evidence that interspecific competition can significantly influence salmon population dynamics and that pink salmon may be the dominant competitor among salmon in marine waters.”
>
> “…analyses demonstrated that overall mortality was greater when sockeye interacted with abundant pink salmon during their second season at sea.”
>
> “Adult returns of four major sockeye salmon stocks declined 22% (from 6.76 ± 0.59 to 5.29 ± 0.62 million fish per stock),on average, during 1977–1997, when they competed with

> abundant odd-year pink salmon during their second season at sea (Ruggerone et al., 2003). This effect represented a cumulative loss of 59 million adult sockeye salmon, excluding the Kvichak River stock whose returns are strongly influenced by a five-year spawning cycle. In light of previous findings that most salmon mortality at sea occurs during early marine life (Pearcy, 1992), it is noteworthy that the analyses of Bristol Bay adult sockeye return data and smolt-to-adult survival data indicate significant mortality also occurred during the second year at sea. The Kvichak River sockeye salmon stock is a major component of the Bristol Bay salmon population and survival of Kvichak River smolts was significantly reduced when they interacted with odd-year pink salmon (Ruggerone et al., 2003). Therefore, we applied the average reduction in adult returns to Bristol Bay (22%) to the average adult return of Kvichak River salmon (average 13.25 million salmon per year) in order to calculate the cumulative total loss of Bristol Bay sockeye salmon. This analysis indicated approximately 32.8 million fewer adult Kvichak River sockeye salmon returned to Bristol Bay when interacting with odd-year pink salmon during their second season at sea, 1977–1997. The total reduction in Bristol Bay sockeye salmon abundance associated with odd-year Asian pink salmon was approximately 91.8 million fish during 1977–1997 (Figure 5). Thus, Asian pink salmon abundance, including the 380% increase in eastern Kamchatka pink salmon abundance between even- and odd-numbered years, was associated with a 35% reduction in sockeye smolt-to-adult survival and a 22% reduction in adult returns."

Azumaya and Ishida (2000) found further evidence of inter-specific interactions between pink and chum salmon in the North Pacific Ocean that could result in harmful impacts to chum salmon:

> "The difference in the density and distribution of chum salmon between odd and even-number years suggested that chum salmon distributions were affected by pink salmon, and shifted from the Bering Sea to the eastern North Pacific as a result of interspecies interaction between pink and chum salmon."
>
> "The distribution of chum salmon shifted from the Bering Sea to the eastern North Pacific, altering densities and growth of chum salmon, when abundance of pink salmon increased in the Bering Sea. This suggests that the abundance of pink salmon influenced the growth of chum salmon indirectly."

King and Beamish (2000) used stomach contents from southern British Colombia to determine that chum salmon are competitors of coho salmon during their first summer in the nearshore marine environment. This competition comes during a life stage when juvenile coho salmon are particularly susceptible to mortality. Their study concluded that body condition of coho was significantly reduced during the period when diet overlap with chum salmon was at its peak. In PWS, salmon fry research conducted by the department has often documented the simultaneous occurrence of juvenile chum, pink, and coho salmon during the summer and fall periods. Therefore, it is reasonable to hypothesize that hatchery chum salmon production in PWS is impacting survival of wild and hatchery produced coho salmon.

Based on a hypothesis put forth by Pearson et al. (1999) and others, Deriso et al. (2008) evaluated hypotheses related to the decline and lack of recovery of Pacific herring in PWS. They concluded:

> "The overall results indicate that the most statistically significant factors related to the lack of recovery of the herring stock involve competition or predation by juvenile hatchery pink salmon on herring juveniles. Secondary factors identified in the analysis were poor nutrition in the winter, ocean (Gulf of Alaska) temperature in the winter, the viral hemorrhagic septicemia virus, and the pathogen *Ichthyophonus hoferi*. The implication of this result to fisheries management in Prince William Sound is that it may well be difficult to simultaneously increase the production of pink salmon and maintain a viable Pacific herring fishery. The impact can be extended to other commercially important fisheries, and a whole ecosystem approach may be needed to evaluate the costs and benefits of salmon hatcheries."

Therefore, in addition to documented deleterious impacts of current levels of hatchery pink salmon production on other salmon species, hatchery production in PWS may also have a deleterious impact on PWS herring. While this hypothesis needs to be explored with additional research, the rapid decline of herring stocks in PWS did occur shortly after a large ramp-up in production of hatchery pink salmon.

Conclusions

A multitude of studies indicate that competitive interactions from large numbers of hatchery pink and chum salmon is occurring in and around PWS and these interactions are likely having a detrimental impact to wild stocks of salmon and herring in the PWS region. Also of concern to department biologists is evidence showing these competitive interactions can significantly reduce yields of high value salmon species such as sockeye, Chinook, and coho salmon. Department research and management biologists, consistent with statutory and regulatory requirements to maintain a precautionary approach to salmon management, advise against additional increases to PWS hatchery pink and chum salmon production.

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