Trophic Interactions and Consumption of Wild Fish and Plankton by Cage-Reared Salmon in British Columbia

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TROPHIC INTERACTIONS AND CONSUMPTION OF WILD FISH AND PLANKTON BY CAGE-REARED SALMON IN BRITISH COLUMBIA

by

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ABSTRACT

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We reviewed the trophic interactions and consumption patterns of cage-reared salmon in British Columbia on naturally occurring wild prey, including wild Pacific salmon and herring. This review involved two approaches: (a) a literature review to identify Canadian and international studies, and (b) compilation and synthesis of published and unpublished results on diets and consumption patterns of cage-reared chinook (*Oncorhynchus tshawytscha)*, coho (*O. kisutch*), steelhead (*O. mykiss*) and Atlantic salmon (*Salmo salar*) salmon on wild prey and ambient variability of fish and plankton surrounding finfish aquaculture sites. The goal of our analysis and review was to comment on the extent of consumption by caged-reared salmonids on wild fish and plankton and potential interaction between finfish aquaculture and wild fish communities in areas around farm sites in coastal British Columbia.

Our review of the literature found no accessible reports concerned with cage-reared salmon feeding and diets on wild prey in Atlantic Canada, Europe and South America farm sites. We consider this to be a knowledge and research gap. Our review did examine results from seven British Columbian studies that have investigated the trophic interactions of cage-reared fish and naturally occurring wild prey. These studies dealt with the interaction of cage-reared salmon and naturally occurring wild prey in farm sites around Vancouver Island, British Columbia. In three of these studies, > 2800 total Atlantic and Pacific (chinook and coho) salmon stomachs were examined for stomach contents collected during April to October, synchronous with movement and large densities of coastal juvenile salmon and Pacific herring populations during spring and summer. Results indicate that both Pacific and Atlantic salmon reared in cages did not routinely consume wild fish and that consumption of fish or plankton was independent of local densities in proximity to farm sites. The most frequently consumed prey items were invertebrates associated with the netpen ‘fouling community’ consisting of capreliids, copepods and gammarids. An exception to this pattern were coho salmon which consumed higher frequencies of wild pelagic fish and invertebrate prey than other cage-reared salmon.

Studies completed to date suggest that cage-reared salmon do consume some naturally occurring wild plankton but at very low frequencies (< 1-5 prey per salmon), and do not routinely consume wild fish. A single sand lance and 29 herring were identified in > 2800 cage-reared salmon stomachs. However, this observation may be biased based on the limited data from cage sites, species and times reported. In many cases salmon were near harvest sizes, or were starved. We do suggest that explicit experiments be developed to comprehensively test hypotheses to verify or reject the impact and magnitude of trophic interactions between cage-reared fish through diel (24 hour

periods) and seasonal periods with wild fish and other natural organisms. Future investigations of trophic interactions between cage-reared fish, netpens and the natural environment should also attempt to integrate many of the important physical and biological elements (netpen structure, siting, local ecosystem) and potential effects of fish farms on local ecosystems.

RÉSUMÉ

Johannes, M.R.S., and Hay, D.E. 2006. Trophic interactions and consumption of wild fish and plankton by cage-reared salmon in British Columbia. Can. Tech. Rep. Fish. Aquat. Sci. 2634: vii + 22 p.

Nous avons étudié les habitudes de consommation de saumons élevés en cage en Colombie-Britannique et leurs interactions trophiques avec les proies sauvages naturellement présentes dans le milieu ambiant, dont les saumons et le hareng du Pacifique. Cet examen comportait deux approches : a) une recherche des études canadiennes et internationales dans la littérature spécialisée; b) une compilation et une synthèse des résultats publiés et inédits sur le régime alimentaire du quinnat (Oncorhynchus tshawytscha), du coho (O. kisutch), du saumon arc-en-ciel (O. mykiss) et du saumon de l'Atlantique (Salmo salar) en conditions d'élevage en cage, ainsi que sur leur consommation de proies sauvages et les fluctuations d'abondance des populations de poissons et d'organismes planctoniques autour des sites aquicoles. Notre objectif était d'évaluer l'importance de la consommation de poissons et d'organismes planctoniques sauvages par les salmonidés élevés en cage et les interactions potentielles entre ces derniers et les communautés de poissons sauvages présentes autour des sites aquicoles dans les eaux côtières de la Colombie-Britannique.

Dans le cadre de notre revue de la littérature, nous n'avons trouvé aucun rapport accessible sur l'alimentation des saumons élevés en cage et leur consommation de proies sauvages dans des sites aquicoles du Canada Atlantique, d'Europe et d'Amérique du Sud. Il s'agit là d'une lacune en matière de connaissances et de recherche. Nous avons examiné les résultats de sept études consacrées aux interactions trophiques entre des saumons élevés en cage et leurs proies sauvages potentielles naturellement présentes dans des sites aquicoles répartis autour de l'île de Vancouver (Colombie-Britannique). Dans trois de ces études, le contenu de plus de 2 800 estomacs entiers de saumons de l'Atlantique et du Pacifique (quinnats et cohos) prélevés entre avril et octobre a été analysé. Cette période coïncide avec le déplacement des populations de saumons juvéniles et de hareng du Pacifique et leur concentration dans les eaux côtières. Ces trois études indiquent que les saumons du Pacifique et de l'Atlantique élevés en cage ne consomment pas régulièrement de poissons sauvages et que leur consommation de poissons ou de plancton n'est pas proportionnelle à la densité de ces proies à proximité des sites aquicoles. Les proies les plus fréquemment consommées étaient des invertébrés associés à la communauté de salissures des parcs en filet, composée de capréliides, de copépodes et de gammarides. La consommation de poissons et d'invertébrés pélagiques sauvages était toutefois plus élevée chez le coho que chez les autres espèces de saumons élevés en cage.

Les études réalisées à ce jour donnent à croire que les saumons élevés en cage incorporent une très faible quantité d'organismes planctoniques sauvages à leur menu

et ne consomment pas régulièrement de poissons sauvages. Seulement un lançon et 29 harengs ont été trouvés dans le contenu stomacal de plus de 2 800 saumons élevés en cage. Cette observation pourrait toutefois être biaisée, étant donné le nombre limité de sites aquicoles, d'espèces et de périodes considérés. Dans bien des cas, les saumons avaient presque atteint l'âge de la récolte ou étaient à jeun. À notre avis, la réalisation d'expériences explicites prévoyant la vérification systématique d'hypothèses devrait être envisagée pour confirmer ou infirmer les effets des interactions trophiques quotidiennes (périodes de 24 heures) et saisonnières entre les saumons élevés en cage et les poissons et autres organismes sauvages présents naturellement dans le milieu ambiant et, le cas échéant, en évaluer l'importance. Les futures études des interactions trophiques entre les poissons élevés en cage, les organismes associés aux parcs en filet, les populations de poissons sauvages et l'environnement naturel devraient également intégrer un grand nombre des caractéristiques physiques et biologiques importantes (structure des parcs en filet, caractéristiques des sites aquicoles et de l'écosystème local) et les effets potentiels des fermes piscicoles sur les écosystèmes locaux.

INTRODUCTION

The development of finfish aquaculture in British Columbia and in the Maritime provinces of Canada has developed rapidly with impetus provided by the decline in harvests of commercially and economically viable wild fish populations especially salmon in British Columbia. This rapid development has led to general concerns about the impacts of aquaculture on wild fish species. For example, in the Canada's Bay of Fundy, it has been suggested that salmon aquaculture may have contributed to declines of local traditional trapping fisheries (herring, lobster, scallops, cod, Pollock and haddock) along coastlines which have depended on historic migration corridors for commercial fish species (Stephenson 1990).

Increased aquaculture fish production has raised specific concerns about potential trophic interactions and consumption by caged –reared fish on sensitive, sometimes at risk (i.e. Slaney et al. 1996), wild fish populations. Little attention has been focused on the potential direct predation impact by cage-reared fish on local or migrating wild populations of fish, for example in British Columbia - migrating juvenile salmonids or other forage species, such as herring or eulachon (c.f. Black et al. 1992, Hay et al. 2004) or sensitive life history stages of wild fish (spawning, larval and juvenile), and plankton communities in proximity to finfish farm sites. Aquaculture farm sites often are selected for efficient water circulation and other physical properties and have lead to siting finfish farms in proximity of important migratory pathways or juvenile nursery habitats for marine and anadromous fish species (Harrison et al. 1983, Levings et al. 1995). Piscivorous salmonid species, such as Atlantic, chinook and coho salmon frequently are chosen as high valued salmon culture species because of their efficient feed / energy conversion and high growth rates (c.f. Naylor et al. 2000). All three species are primarily piscivores in feeding habitat during their marine life history stages (i.e. chinook salmon - Healey 1991, coho salmon- Sandercock 1991, Atlantic salmon – Mills 1989, Hislop and Webb 1992, Jacobsen and Hansen 2001). Studies in B.C. have examined the potential effects of piscivorous cage-reared salmon consuming juvenile stages of migrating fish, especially wild salmon and local populations of other fish species (Gillis et al. 1989, Gillis 1991, Black et al. 1992, Miller and Black 1992, Black and Miller 1993, Hay et al. 2004). Anecdotal observations of salmon farms suggest that large schools or juvenile salmon or herring are seen in close proximity of cages (c.f. Gillis 1991, Hay et al. 2004).

The objectives of our report are to: (1) review the literature to identify studies of trophic interactions between cage-reared fish and natural occurring prey, (2) provide a synthesis of past studies on feeding patterns by cage-reared salmon in B.C. on naturally occurring wild fish and plankton prey, and (3) identify potential knowledge gaps about the impacts and risks of finfish aquaculture to local or migrating wild fish to predation by cage-reared fish.

Our report has two sections. The first provides a literature review to identify Canadian and International studies that examine trophic interactions and consumption of cage-reared fish on naturally occurring prey. The second part summarizes the results from three field studies (1989, 1991, 1995) which examine the diet of cage-reared chinook (*Oncorhynchus tshawytscha)*, coho (*O. kisutch),* steelhead (*O. mykiss)* (Gillis et al. 1989, Black et al. 1992) and Atlantic (*Salmo salar)* salmon (Hay et al. 2004) on natural wild fish and plankton prey.

2.0 MATERIALS AND METHODS

2.1 Literature Review

We compiled a database of available literature as background and review based on search for cage-reared fish, salmon, aquaculture, natural food and prey. The literature database includes records compiled based on key words and phrases including: aquaculture, "finfish" aquaculture, netpen, cage, fish farming, predation, trophic, natural prey, environment and salmon. The database was constructed in Endnote © software through direct link, search and download from existing literature search data engines including: WAVES (DFO), Web of Science, Aquatic Sciences and Fisheries Abstracts, Applied Science Index, Biological Science Index, and Science Direct, plus local collections at the University of Victoria, Malaspina University College, University of British Columbia and Fisheries and Oceans - Pacific Biological Station. The literature database is a compilation of many available information sources.

The database identifies literature based on reference type (journal article, book, report etc.), keywords, author, title, publisher (journal), and abstract. We searched our constructed "aquaculture" literature database based on: reference type, location or region both within Canada and internationally, trophic interaction, fish species and potential wild prey.

There are several sources of uncertainty that apply to this literature review. The database provided a representative, rather than exhaustive, compilation of information and literature sources, so that the state of knowledge was potentially under represented. Many search engines were used to explore and retrieve literature from various collections, however the full extent of literature on the interactions of cage-reared fish and wild prey remains unknown.

2.2 Review of Field Studies

Our synthesis was derived from three field studies on the consumption by cage-reared salmon on natural or wild prey (Table 1, 2). These data include analysis of stomach contents from:

- 1634 chinook salmon collected in 1989, from nine Vancouver Island farm sites;
- 60 coho salmon, collected in 1989, from one Vancouver Island farm site;
- 10 steelhead salmon, collected in 1989, from one Vancouver Island farm site;

- 424 chinook salmon, collected in 1991, from one Vancouver Island farm site;
- 734 Atlantic salmon, collected in 1995, from five Vancouver Island farm sites.

Data on wild fish and plankton densities were extracted from these and other studies include:

- 82 plankton samples collected in 1989 from eight Vancouver Island farm sites concurrent with stomach sampling;
- 47 purse seine samples of fish collected in 1989 from the same eight Vancouver Island farm sites concurrent with stomach and plankton sampling;
- 45 beach seine samples of fish collected in 1991 (data not available), and
- 13 plankton samples collected in 1995, from two Vancouver Island farm sites concurrent with stomach sampling.

Detailed methods on farm site location, general sampling techniques and stomach content analysis are found in the original source studies (Table 1, 2) and are briefly reproduced here (Gillis et al. 1989, Haegele et al. 1991, Gillis 1991, Black et al. 1992, Hay et al. 2004).

In the original studies of caged-reared Pacific salmon, sampling sites were chosen according to their proximity either to Pacific herring spawning or nursery areas, or migratory routes for pink and chum salmon juveniles in the Broughton Archipelago, Burdwood Island, Queen Charlotte Strait, and around Quadra and Cortez Islands of Vancouver Island. Caged Atlantic and Pacific salmon captured for stomach analysis were sampled using hook-and-line (done at the farm operators' requests to minimize disturbance), but at some farm sites stomachs were sampled from fish as they were freshly harvested for market (Gillis et al. 1989, Gillis 1991, Hay et al. 2004). About 20 salmon were sampled on a single day from each site. Sample data included date, time of day, species, sex, total fish weight (nearest 10 g), and fork length (mm). Stomachs were removed and preserved individually in self-sealing plastic bags with equal volumes of 8 % buffered formalin. Stomachs and contents were individually weighed to derive stomach content weight. Organisms were separated from salmon feed - pellet residue when present. Wild prey organisms were identified, enumerated, and weighed (Gillis et al. 1989). Estimates of fish and zooplankton available to caged-reared salmon were made by direct observation, purse and beach seining, scraping the cage net to sample the fouling community, and using towed bongo nets (Haegele et al. 1991).

Analyses of wild fish communities were made by purse seine sampling in the vicinity of Pacific salmon farm sites (1989, 1991). Seine catches were sorted by species and samples preserved in 10% formalin. Preserved fish were identified, counted, measured (mm) and weighed (g). Open water plankton were sampled around fish sites were made with small Bongo nets (19cm net opening diameter and 0.35 mm mesh) that sampled the upper 20 m in oblique hauls. Filtered volumes were estimated with a flowmeter in the net opening. Zooplankton catches were preserved in 10% formalin and later analyzed in the laboratory (Haegele et al. 1991).

Studies of Atlantic salmon predation were conducted in the southern Queen Charlotte Strait area on lighted and unlighted farms (Hay et al. 2004). This area is topographically complex, with a diversity of habitats used by migratory marine species such as salmon juveniles, eulachons, and juvenile herring. Twenty Atlantic salmon were sampled each week using dip nets from each farm, from the first week of May to the second week of July (Table 1). Data collection of sampled fish and stomachs contents were similar to the methods used for Pacific salmon (above). Some additional Atlantic salmon were sampled at a processing plant in Hardy Bay and from the experimental facility at the Pacific Biological Station, Nanaimo.

A spatial and temporal analysis of the spatial and temporal aspects of cage-reared Pacific and Atlantic salmon consumption of wild prey was done according to farm location. This analysis was not completed in the earlier presentation of these data. Sites were labeled as either “main channel” or “off channel” based on statistical differences examined through an analysis of variance (ANOVA) and similarities between mean consumption of wild prey between site locations. No physical / environmental data was available for these sites.

3.0 RESULTS

Our results comprise two components: 1) a review of the literature, and 2) summary of existing field studies on consumption of wild prey by cage-reared salmon.

3.1 Literature Review

We compiled an extensive database of available literature as background and review for cage-reared fish, salmon, aquaculture, natural food and wild prey. The literature database (dated Dec. 2005) includes >5,300 accumulated records compiled based on key words and phrases. Our review produced the following results.

A. The majority (4,809) of the records related to various aspects of aquaculture and 4,196 specifically with salmon aquaculture.

B. 931 records were related to “net pens”, “cage” and “salmon and farm”, but involved various aspects of aquaculture including feed delivery systems, sea lice, site selection, quality control, diseases, ecosystem and environmental issues associated with farm site location, nutrient loading, wild fish communities and cage-reared fish impacts and escape issues.

C. 154 records were identified and related specifically to interactions of cage-reared fish with their natural environments.

D. 78 records related to trophic interactions of finfish aquaculture with wild fish.

E. 30 records examined attraction and distribution of wild fish populations associated finfish farm sites.

F. 20 records related to cage-reared salmon feeding within cages and as escaped fish in the wild.

G. 14 records studies feeding patterns of escaped aquaculture in the wild.

H. Of these records, 7 references (Table 1) specifically identified experiments or evidence examining the interaction or consumption of wild prey by cage-reared salmon. Four of these papers are published reports and summaries, and the remaining two reports (Gillis et al. 1989, Gillis 1991) are unpublished.

Table 1 summaries the extent of existing studies examining the potential effects of cage-reared fish on naturally occurring wild prey, and local environments and ecosystems in proximity to farm sites. A more detailed review of these literature are provided in Johannes (2006).

3.2 Synthesis of Field Studies of Predation by Cage-Reared Salmon

Our synthesis of field study results in B.C. can be classified into three components results. First, patterns of wild prey consumption by cage-reared salmon and local natural prey patterns of abundance; second, the relationship between cage-reared fish size and wild prey consumption, and third, the association between cage-reared fish starvation and wild prey consumption. A summary of the estimated total number of prey per salmon and diet composition of cage-reared chinook (Gillis et al. 1989, Haegle et al. 1991, Black et al 1992) and Atlantic salmon (Hay et al. 2004) are shown in Table 3 and 4 respectively. For each species we show: (1) mean number of wild prey consumed per salmon stomach, (2) sample sizes, (3) prey composition (%) in salmon stomachs, and (4) composition (%) of wild potential prey in plankton samples and fish seining. The feeding patterns of cage-reared chinook, coho and Atlantic salmon and, where available, patterns of fish and plankton density in proximity to farm sites (Fig. 2, 3) were derived from Gillis et al. (1989), Haegele (et al. 1991), Black et al. 1992 and Hay et al. (2004). Data presented in these studies include the size (length) frequency distribution of chinook, coho and Atlantic salmon and presence or absence (with and without) of wild prey in stomach samples (Fig. 4). The association between the starvation period in days and number of prey consumed by chinook salmon is shown in Fig. 5.

The stomach content analysis revealed that salmon consume on average < 5 prey organisms per stomach sample with a range of 0 to 7.75 prey per stomach (Fig. 2, 3; Table 3, 4). Coho salmon had the highest total number of wild prey consumption (0.55 to 7.75 prey per stomach) followed by chinook salmon (0.11 to 4.76), rainbow trout (1.1) and Atlantic salmon (0 to 5.4). Coho salmon had also the highest total number of wild fish consumed (1.6 wild fish per stomach) followed by chinook (0.17), Atlantic salmon (<0.01) and rainbow trout (0). Twenty-eight juvenile Pacific herring and a single sand lance were identified in stomachs. The most common wild prey items found in stomachs were caprellids, followed copepods (and nauplii), crab zoea, euphausiids, amphipods and gammarids. Capreliids, amphipods, and gammarids are periphyton species often found living in the flora / fauna commonly growing on netting in cages. The frequency of invertebrates to fish consumed by cage-reared salmon was always higher (Fig. 1).

Chinook salmon, from a number of similar main channel fish farm sites, and coho salmon showed seasonal patterns of increased wild prey consumption (April to July) (Fig. 2). Higher rates of plankton and fish consumption by chinook and coho was inverse to the seasonal patterns of wild plankton and fish densities. Wild plankton and fish densities in proximity to farm sites declined over the summer growing season. There appears to be a general pattern between higher density of wild plankton or fish in the vicinity of farm sites and higher wild prey consumption by salmon. Although Atlantic salmon do not show a seasonal pattern of consumption (Fig. 3), Larsen Island Atlantic salmon maintain higher wild prey consumption consistent with higher wild plankton densities relative to Deep Harbour. Similarly, "main channel" chinook showed higher wild prey consumption than "off channel" chinook, which was also consistent with higher ambient wild prey densities. It is not clear if this association is spurious, resulting in part from low sample size. Even so, total consumption of wild prey organisms is very low. There is no obvious relationship between size of individual cage-reared salmon, by species, and the presence or absence of wild prey in stomach samples (Fig. 4). Greater than 50% of the Atlantic and chinook salmon did not contain evidence of wild prey. Coho salmon showed no discernable relationship of consumption and fish size, but greater than 50% of the salmon stomachs contained wild prey.

At the time of field collections from farms, it was common to withhold pellet food from cage-reared salmon in order to clear guts of undigested and partially digested matter prior to marketing. Review of the field data on wild prey consumption by chinook salmon in 1989, from eight Vancouver Island farm sites indicates a positive association (r^2=0.47, $p<0.01$) between number of days starved and the number of wild prey consumed (Fig. 5). No results were available for starved Atlantic, steelhead and coho salmon.

DISCUSSION

Our literature review suggests that three key predation and competitive processes comprise the principal trophic interactions between cage-reared fish and the natural environment include: (a) direct consumption and impact on wild fish and plankton by cage-reared fish, (b) attraction and potential production increases of wild fish and plankton around farm sites associated with pellet surplus and loss, enhanced refuge provided by farm site facilities, and (c) consumption and impacts of escaped farm fish with wild fish populations . We do not examine (b) and (c) in this document. Johannes (2006) provides a review of all three key predation and competitive trophic interactions between cage-reared and wild fish. We also do not examine other potential trophic level interactions between cage-reared fish and the environment such as those associated with escaped fish or impacts of disease or parasites. These interactions were considered beyond the scope of this study and are reviewed extensively in the Fisheries and Oceans Canada State of Knowledge (Fisheries and Oceans 2003) documents and Weir and Grant (2005).

Results compiled from seven B.C. studies indicate that the consumption of wild prey by individual cage-reared Chinook, coho, steelhead and Atlantic salmon averaged below 5 wild prey per salmon with limited range in selection of wild prey type. Cage-reared salmon rarely consumed wild fish attracted to cages, although observations and fish surveys indicate high densities of juvenile pink and chum salmon, Pacific herring and sand lance in proximity to cage sites (c.f. Gillis et al 1989, Gillis 1991, Hay et al. 2004). Chinook salmon did show some different patterns in wild prey consumption between main current channel sites relative to sites in more confined off channel areas. Two of the seven studies examined the consumption of wood debris by cage-reared salmon in proximity to source of forest products including pulp mills (Miller and Black 1992, Black and Miller 1993).

The patterns and rates of wild prey consumption varied among and within salmon species, individuals within cages, seasons and west coast farm sites. Caprellids were most commonly consumed by chinook and Atlantic salmon species. Capreliids are invertebrates abundant in the periphyton "fouling" community on cage netting. There was little evidence of fish or fish larvae consumption by individual cage-reared chinook and Atlantic salmon. Chinook and Atlantic salmon, and steelhead (Gillis et al. 1989) showed that < 50% of cage-reared salmon (population) consumed wild prey, while 55% (n=60) of the coho salmon consumed wild prey. Coho salmon showed much higher preferences for wild fish prey and most commonly consumed herring, followed by capeliids and gamarids. No juvenile salmonids were found in any stomach samples. Greater than 35% of chinook, >20% of coho and <5% of Atlantic salmon consumed 5 wild prey per individual salmon suggesting a skewed distribution of consumption by individual salmon within a cage and among salmon species. Our synthesis show no association between salmon size by species and frequency of wild prey consumption.

Similarly, chinook raised at specific farm sites identified as "main channel" locations, and coho salmon, showed patterns of increased consumption of wild prey across the summer growing season. Atlantic salmon, steelhead and "off channel" chinook showed no pattern of wild prey consumption. Higher consumption rates by site specific chinook and coho salmon were found to be coincident to higher local densities of fish and plankton in the vicinity of farm sites. We found no evidence to support or refute the association between wild prey consumption by cage-reared salmon and prey densities inside and outside net pens, age or level of fouling in net pens, or the frequency of net pen cleaning. Field observations of cage-reared Atlantic salmon which have escaped net pens, have shown that escape salmon adapt well and show similar feeding patterns and growth rates to wild Atlantic salmon (Hislop and Webb 1992, Hansen et al. 1997, Brodeur and Busby 1998, Andreassen et al. 2001, Jacobsen and Hansen 2001, Morton and Volpe 2002, McKinnell et al. 1997).

Hay et al. (2004) also showed results which suggested that wild prey consumption by Atlantic salmon was not related to continuous lighting conditions experienced in net pens. Lighted conditions were expected to attract greater concentrations of wild potential prey to net pens and enhance feeding opportunities by cage-reared salmon.

Normal operations in salmon farms usually starve fish prior to harvest. Hunger associated pre-harvest starvation may increase consumption of wild prey by cage-reared salmon. Salmon harvesting from net pens occurs only every 18-36 months. Our review suggests that wild prey consumption by chinook salmon declines initially while starved fish may attempt to conserve energy, but that salmon starved greater than 15 days showed increased consumption of wild prey.

Hay et al. (2004) suggested that limitations in timing and frequency of sample collection could produce low biased estimates of wild fish and plankton numbers in stomach samples per individual salmon. They suggested that the analysis of hundreds of salmon stomachs detected few fish scales or fragments as evidence of wild fish predation by cage-reared salmon. Hay et al. (2004) also suggested that collected stomach content weights relative to body were low and did not reflect appropriate levels of fullness to predict sampled salmon growth at the time of collections. They suggested stomach samples may do not reflect normal feeding patterns and conditions of salmon in cages and that future studies will need to address this issue.

The objective of our review was to examine patterns of consumption of wild prey by cage-reared salmon. Seven studies in B.C. were found which explicitly examined this question. We can conclude that cage-reared salmon from these studies consume few wild prey and little no wild fish. However, the results are not conclusive and additional study is needed. We suggest that future research examine trophic interactions between cage-reared fish and naturally occurring potential prey to include more comprehensive diel, seasonal and site specific diet sampling. In many cases the salmon examined were captured by use of hook and line gear using mimic herring spoons. Sampling should include gear, times of day and season and combinations of sites which are independent of potential sampling bias. Live stomach content sampling technique called gastric lavage should be used as an alternative to sacrificing fish during sampling (c.f. Light et al. 1983). Future study should include experimental approaches which would sample “individual” salmon to examine patterns of consumption and use these results to extrapolate or model (i.e. bio-energetic) to the farm site fish “population” level pattern of consumption and impact on wild prey populations. We suggest that future research experimental or empirical design should incorporate: a) farm site location, b) diel sampling, c) seasonal sampling, d) net pen state variables (clean / fouled), size, depth, location, e) lighting conditions, f) fish size, and g) fish starvation condition. Parallel to diet sampling of cage-reared fish, should be the requirement to quantitatively sample wild fish and plankton densities inside and outside multiple net pens.

Our main conclusions are that the “individual” cage-reared salmon consume few number of wild fish or plankton. Given the results examined, we were unable to extrapolate the potential impact from the entire “population” of cage-reared fish on wild prey. We found that the most common wild organisms consumed were caprellids, which live on the side of net pen cages. We found few fish in the gut samples, most of those were juvenile herring. We cannot rule out the possibility that some larval stages of fishes were consumed and digested. Most larval fish are quite small (<1cm) in length and may not be recognizable in gut contents, even after short periods (< 1 hour) of digestion. None were noted in stomachs from cage-reared salmon analyzed for gut contents. However, if fish were frequently consumed, they might not have been recognizable, even after very short periods of digestion.

KNOWLEDGE GAPS

Further study and integration of the major pathways and interactions between finfish farm site and caged finfish and natural ecosystems and biotic will require substantial research effort. A thorough investigation would entail analysis of interactions between cage-reared salmon and wild prey, analysis of wild predators to examine nutrient and energy sources, identification and quantifications of sinks and pathways across trophic levels. From additional analysis of the available literature, research methods for investigation of these pathways could involve:

1. empirical observation of caged-reared consumption patterns and wild prey and predator in situ densities and biomass between multiple farm sites over time (c.f. Hay et al. 2004);

2. experimental manipulation of cage-reared salmon densities, size structure, cage design, fish species in farm site locations in association with naturally occurring prey and predator species mixes over time;

3. isotope markers and fatty acid analysis used to trace forms of nutrients in farm sites to identify sources and sinks of energy and nutrient pathways between naturally occurring trophic levels and cage-reared salmon (e.g. Sutherland et al. 2001, Skog et al. 2003, Sara et al 2004); and

4. mass balance and bioenergetics approaches to model and predict nutrient and energy input and output rates across trophic levels with caged-reared salmon (e.g. Troell and Norberg 1998).

Our literature review indicates that such analysis of whole ecosystems and trophic level interaction-based studies have not yet been undertaken in any aquaculture systems. Mass balance studies have been used to model the energy transfer to cage-reared fish (i.e. Stewart and Grant 2002), but have not examined trophic level interactions with naturally occurring prey and predators.

An ongoing study to examine interactions between cage-reared finfish and natural ecosystems would involve monitoring changes in farm technology (i.e. lights, net pen design) and ecosystems around farms, both for natural and anthropogenic causes. Such future investigations would be expensive. On the other hand, some recent advances in farm technology could reduce or eliminate interactions between cage-reared fish and local ecosystems and may provide a less expensive alternative to the studies suggested above.

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Table 1: Summary of existing studies on the trophic interactions of cage-reared salmon on wild fish and plankton in B.C.

Summary of Results	**Literature Source**
• Chinook, coho, steelhead salmon diet analysis and consumption of wild prey	Gillis et al. 1989 Unpublished Report
• Wild prey distribution and density in association with farm site identified by Gillis et al. 1989	Haegele et al. 1991. Published Tech. Report
• Chinook salmon consumption of wild prey	Gillis 1991 Unpublished Report
• Summary analysis of Gillis et al. 1989, and Gillis 1991. Chinook salmon consumption of wild prey	Black et al. 1992. Conference Proceedings.
• Chinook salmon consumption of wood debris	Miller and Black 1992 Conference Proceedings, Black and Miller 1993 Published Article
• Atlantic salmon consumption of wild prey under lighted / unlighted caged rearing conditions	Hay et al. 2004. Published Tech. Report

Table 2: Summary of data and reports compiled for analysis of consumption patterns of cage-reared chinook, coho, Steelhead and Atlantic salmon on naturally occurring wild prey items in coastal areas of British Columbia.

SPECIES	Date	Location	Sample Size	Source
Chinook Salmon		Distance To Shoreline / Water Depth		
Main Channel	20/4/89 to 11/7/89	Waiatt Bay, Quadra Island, South Okisollo Channel, B.C. 220m 22m	239 Stomach Samples Diet Analysis Local Zooplankton Samples Local Fish Netting	Gillis et al. 1989 Unpublished Report Haegele et al. 1991
	19/4/89 to 28/6/89	Yellow Island, Quadra Island, Seymour Narrows, B.C. 45m 28m	56 Stomach Samples Diet Analysis Local Zooplankton Samples Local Fish Netting	Gillis et al. 1989 Unpublished Report Haegele et al. 1991
	19/4/89 to 11/7/89	Kanish Bay, Quadra Island, B.C. 200m 18m	239 Stomach Samples Diet Analysis Local Zooplankton Samples Local Fish Netting	Gillis et al. 1989 Unpublished Report Haegele et al. 1991
	22/4/89 to 25/6/89	Surge Narrows, Quadra Island. North Hoskyn Channel, B.C. 60m 35m	240 Stomach Samples Diet Analysis Local Zooplankton Samples Local Fish Netting	Gillis et al. 1989 Unpublished Report Haegele et al. 1991
	21/4/89 to 10/7/89	Conville Point, Quadra Island. North Hoskyn Channel, B.C. 75m 32m	200 Stomach Samples Diet Analysis Local Zooplankton Samples Local Fish Netting	Gillis et al. 1989 Unpublished Report Haegele et al. 1991
	22/4/89 to 30/4/89	Quartz Bay, Cortez Island, Sutil Channel, B.C. 40m 15m	40 Stomach Samples Diet Analysis Local Zooplankton Samples Local Fish Netting	Gillis et al. 1989 Unpublished Report Haegele et al. 1991
Off Channel	21/4/89 to 9/7/89	Village Bay, Quadra Island, Hoskyn Channel, B.C. 95m 31m	200 Stomach Samples Diet Analysis Local Zooplankton Samples Local Fish Netting	Gillis et al. 1989 Unpublished Report Haegele et al. 1991
	20/4/89 to 20/6/89	Okisollo, Sonora Island, North Okisollo Channel, B.C. 125m 16m	200 Stomach Samples Diet Analysis Local Zooplankton Samples Local Fish Netting	Gillis et al. 1989 Unpublished Report Haegele et al. 1991
	22/4/89 to 10/7/89	Ramsay Arm, Desolation Sound, Calm Channel, B.C. 75m 20m	219 Stomach Samples Diet Analysis Local Zooplankton Samples Local Fish Netting	Gillis et al. 1989 Unpublished Report Haegele et al. 1991
Coho Salmon				
	7/6/89 to 28/6/89	Yellow Island, Quadra Island, Seymour Narrows, B.C. 45m 28m	60 Stomach Samples Diet Analysis Local Zooplankton Samples Local Fish Netting	Gillis et al. 1989 Unpublished Report Haegele et al. 1991
Steelhead Salmon				
	10/5/89	Yellow Island, Quadra Island, Seymour Narrows, B.C. 45m 28m	10 Stomach Samples Diet Analysis Local Zooplankton Samples Local Fish Netting	Gillis et al. 1989 Unpublished Report Haegele et al. 1991
Chinook Salmon				
	15/4/91 to 15/5/91	Burwood Island, Queen Charlotte Strait, B.C.	424 Stomach Samples Diet Analysis Local fish netting	Gillis 1991, Black et al. 1992

Table 2 cont.: Summary of data and reports compiled for analysis of consumption patterns of cage-reared chinook, coho, Steelhead and Atlantic salmon on naturally occurring wild prey items in coastal areas of British Columbia.

Atlantic Salmon				
	9/5/95 to 13/7/95	Deep Harbour Queen Charlotte Strait, Broughton Archipelago, B.C.	180 Stomach Samples Diet Analysis Local Zooplankton Samples	Hay et al. 2004
	9/5/95 to 12/7/95	Larsen Island Queen Charlotte Strait, Broughton Archipelago, B.C.	180 Stomach Samples Diet Analysis Local Zooplankton Samples	Hay et al. 2004
	6/6/95 to 11/7/95	Raynor Group Port Hardy area, B.C.	40 Stomach Samples Diet Analysis Singe Zooplankton Sample	Hay et al. 2004
	20/6/95 to 4/7/95	Shelter Passage Port Hardy area, B.C.	240 Stomach Samples Diet Analysis	Hay et al. 2004
	27/7/95 to 10/10/95	Departure Bay Nanaimo, B.C.	134 Stomach Samples Diet Analysis	Hay et al. 2004

Table 3: Frequency of cage-reared salmon with wild prey (fish and invertebrates) in stomach samples for Chinook salmon main, off channel and northern farms (Table 2), coho, steelhead and Atlantic salmon from 1989, 1991 and 1995 collections.

Salmon Species / Location	Year	Stomachs Sampled	Stomach with wild fish # *	%	Stomachs with wild invertebrates # *	%	Stomachs with no wild prey #	%
Chinook Main Channel	1989	1014	10	1.0	491	48.4	529	52.2
Chinook Off Channel	1989	620	7	1.1	116	18.7	507	81.8
Chinook North	1991	424	0	0	23	5.4	403	95
Coho Off Channel	1989	60	12	20.0	35	58.3	27	45
Steelhead Off Channel	1989	10	0	0	3	30.0	7	70
Atlantic	1995	734	1	0.1	31	4.2	709	96.6

* Stomach sample can include both fish and invertebrate prey.

Table 4: Comparison of estimates of chinook salmon diet composition (%) of wild prey compared with ambient plankton and fish species densities (%) collected from Main Channel and Off Channel Johnston Strait fish farm sites in 1989. (Data derived from Gillis et al. 1989, Haegele et al. 1991).

Plankton / Fish Species	Main Channel Caged Salmon Wild Prey Diet (%)	Main Channel Plankton Density (%)	Main Channel Fish Density (%)	Off Channel Caged Salmon Wild Prey Diet (%)	Off Channel Plankton Density (%)	Off Channel Fish Density (%)
Sample Size	N=1124 (Stomachs)	N=62 (Hauls)	N=30 (Seine Nettings)	N=631 (Stomachs)	N=20 (Hauls)	N=10 (Seine Nettings)
Mean Wild Prey (#) / Salmon	2.98 ± 0.51			0.74±0.34		
Plankton						
Amphipod		0.5			0.8	
Barnacle	0.4	1.5		5.4	0.7	
Caprellid	52.0			47.8		
Claodoceran		0.7			3.3	
Copepod	0.8	20.3		7.9	22.5	
Crab Zoea	0.9	4.4		0.6	13.2	
Ctenophore		0.4			0.9	
Eggs		22.3			2.5	
Euphausiid Zoea		6.5			5.2	
Euphausiid Adult	4.7	1.8		0.6	3.3	
Gammarid	36.3			11.2		
Gastropod						
Hyperid	0.2					
Larvacean		18.4			25.8	
Mytilus	0.7			9.8		
Medusae		0.4			0.5	
Nauplii		23.0			20.	
Nematode	0.5			1.6		
Oikopleura						
Polychaete		0.5			0.5	
Pteropod		0.1			0.2	
Shrimp Zoea						
Fish						
Chinook juvenile			1.4			31.4
Chum juvenile			7.1			31.4
Coho juvenile			0.6			8.6
Herring juvenile	3.5		59.0	15.1		10.0
Herring Adult			12.0			
Kelp Greenling						5.7
Lingcod			1.3			
Pink juvenile			16.3			
Rockfish sps.						1.4
Sand Lance						7.1
Shiner Perch			1.4			
Sockeye juvenile			1.3			2.9
Stickleback						1.4
	100%	100%	100%	100%	100%	100%

Table 5: Comparison of estimates of Atlantic salmon diet composition (%) of wild prey compared with ambient plankton species densities (%) collected from Larsen Island and Deep Harbour fish farm sites in 1995. (Data derived from Hay et al. 2004).

Plankton / Fish Species	Larsen Island Caged Salmon Wild Prey Diet (%)	Larsen Island Plankton Density (%)	Larsen Island Cage Web Plankton Density (%)	Deep Harbour Caged Salmon Wild Prey Diet (%)	Deep Harbour Plankton Density (%)	Deep Harbour Web Plankton Density (%)	Port Hardy Area Caged Salmon Wild Prey Diet (%)
Sample Size	N=180 (Stomachs)	N=7 (Hauls)	N=2 (Sample)	N=180 (Stomachs)	N=6 (Hauls)	N=2 (Sample)	N=374 (Stomachs)
Mean Wild Prey (#) / Salmon (Mean±95%CI)	0.57±0.63			0.005±0.01			0.65±1.0
Plankton							
Amphipod		1.0	0.2		12.7	0.01	
Barnacle		0.6	0.3	25.0	0.9	0.16	
Caprellid	76.2		13.5			0.09	91.0
Claodoceran		4.9	0.6		5.0	0.63	
Copepod		33.3	9.1		13.6	11.9	2.3
Crab Zoea	22.7	3.8	0.8	37.5	17.1	0.04	2.0
Ctenophore							
Eggs							
Euphausiid Zoea		0.4			0.3		
Euphausiid Adult							
Gammarid	0.6			25.0			3.7
Gastropod		2.5	0.2		3.5		
Hyperid							
Larvacean							
Mytilus							
Medusae		1.8			6.1	<<0.01	
Nauplii		48.4	75.3		38.4	86.5	
Nematode	0.6						
Oikopleura		2.2			0.6	0.63	
Polychaete						0.01	
Pteropod							
Shrimp Zoea		1.0			1.8		
Fish							
Chinook juvenile							
Chum juvenile							
Coho juvenile							
Herring juvenile				12.5			0.4
Herring Adult							
Kelp Greenling							
Lingcod							
Pink juvenile							
Rockfish sps.							
Sand Lance							
Shiner Perch							
Sockeye juvenile							
Stickleback							
Teleost Larvae							
	100%	100%	100%	100%	100%	100%	100%

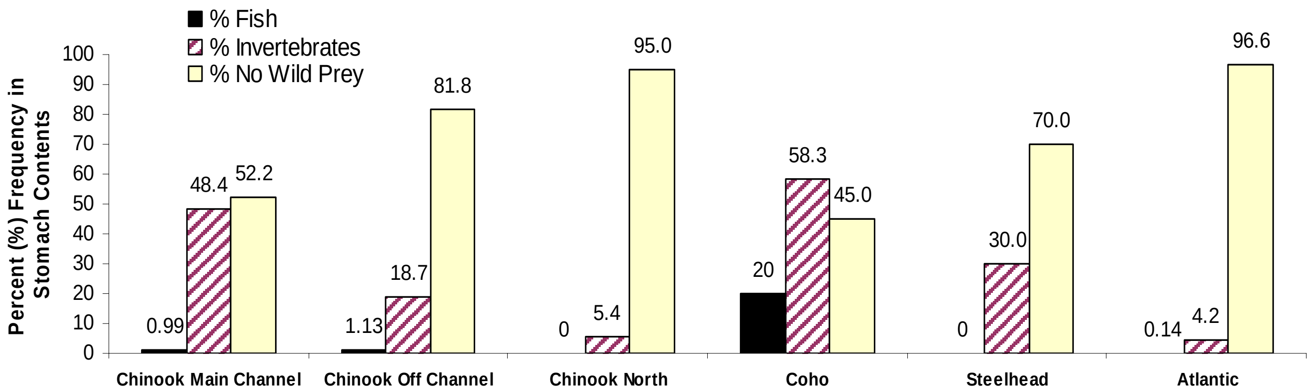

Figure 1: Percent frequency of wild prey items consumed by cage-reared Chinook in Main and Off Channel areas of Quadra Island, Chinook North in Burdwood Island, Queen Charlotte Strait, and coho and steelhead from Off Channel areas of Quadra Island, and Atlantic salmon from Queen Charlotte Strait and a small set of Atlantic salmon from Departure Bay. Samples size and years of collection are presented in Table 2, 3. Numeric percents are given in figure.

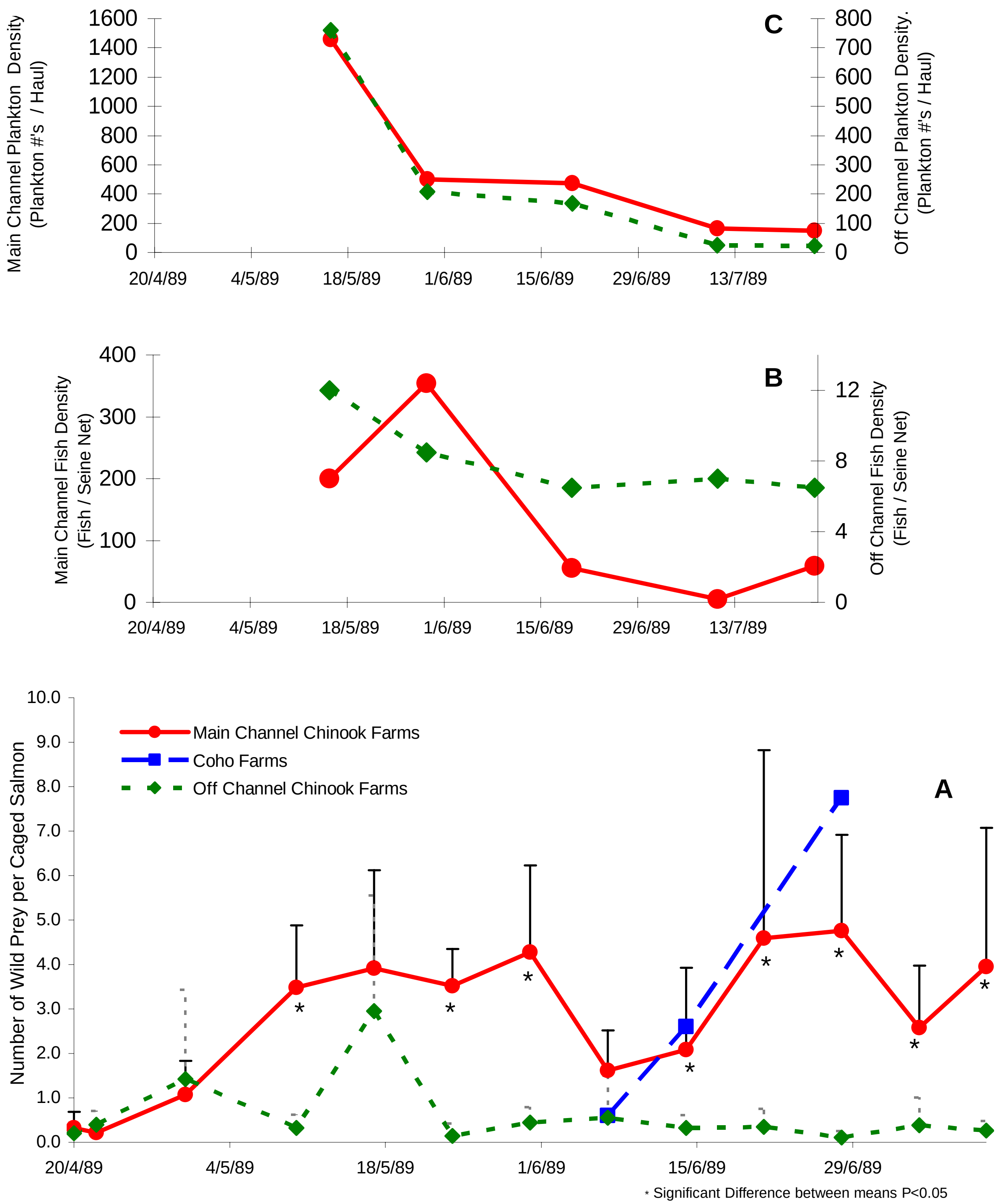

Figure 2: **A** - Mean number of wild prey items (+95% CI) consumed by cage-reared chinook and coho salmon across the sampling period during 1989. * identifies significant differences (P< 0.05) between mean wild prey items consumed from chinook salmon in “main” and “off” channel farms (Table 2). (Data from Gillis et al. 1989). **B** - Mean wild fish density (# of fish / seine) in 1989. ay). **C** - Mean wild plankton density (# of plankton / haul) in 1989. (**B** & **C** data from Haegele et al. 1991).

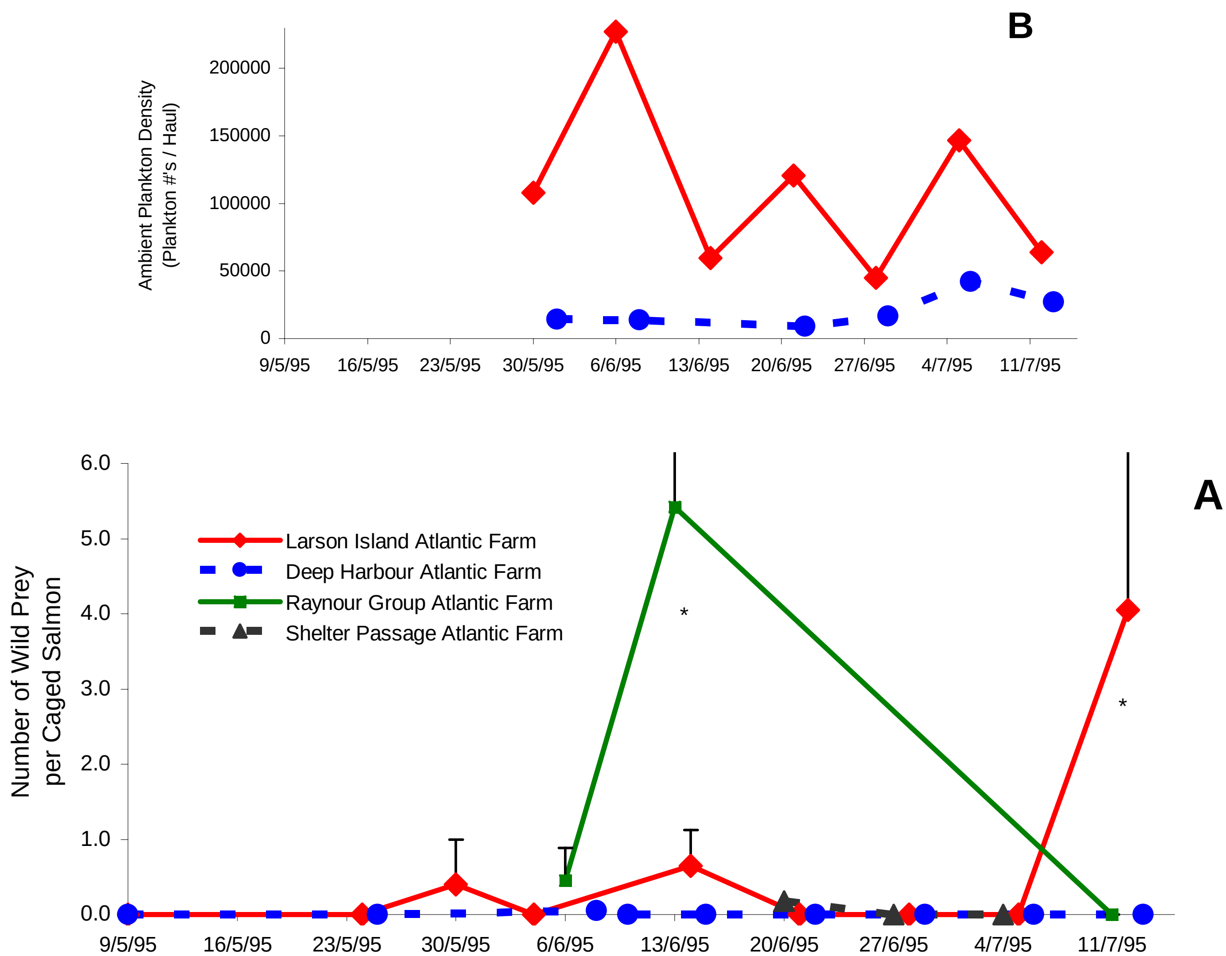

Figure 3: **A -** Mean number of wild prey items (+95% CI) consumed by Atlantic salmon across the sampling period during 1995. * identifies significant differences (P< 0.05) between mean wild prey items consumed from Atlantic. **B** - Mean plankton density (# of plankton / haul) from Larsen Island and Deep Harbour. (Data from Hay et al. 2004).

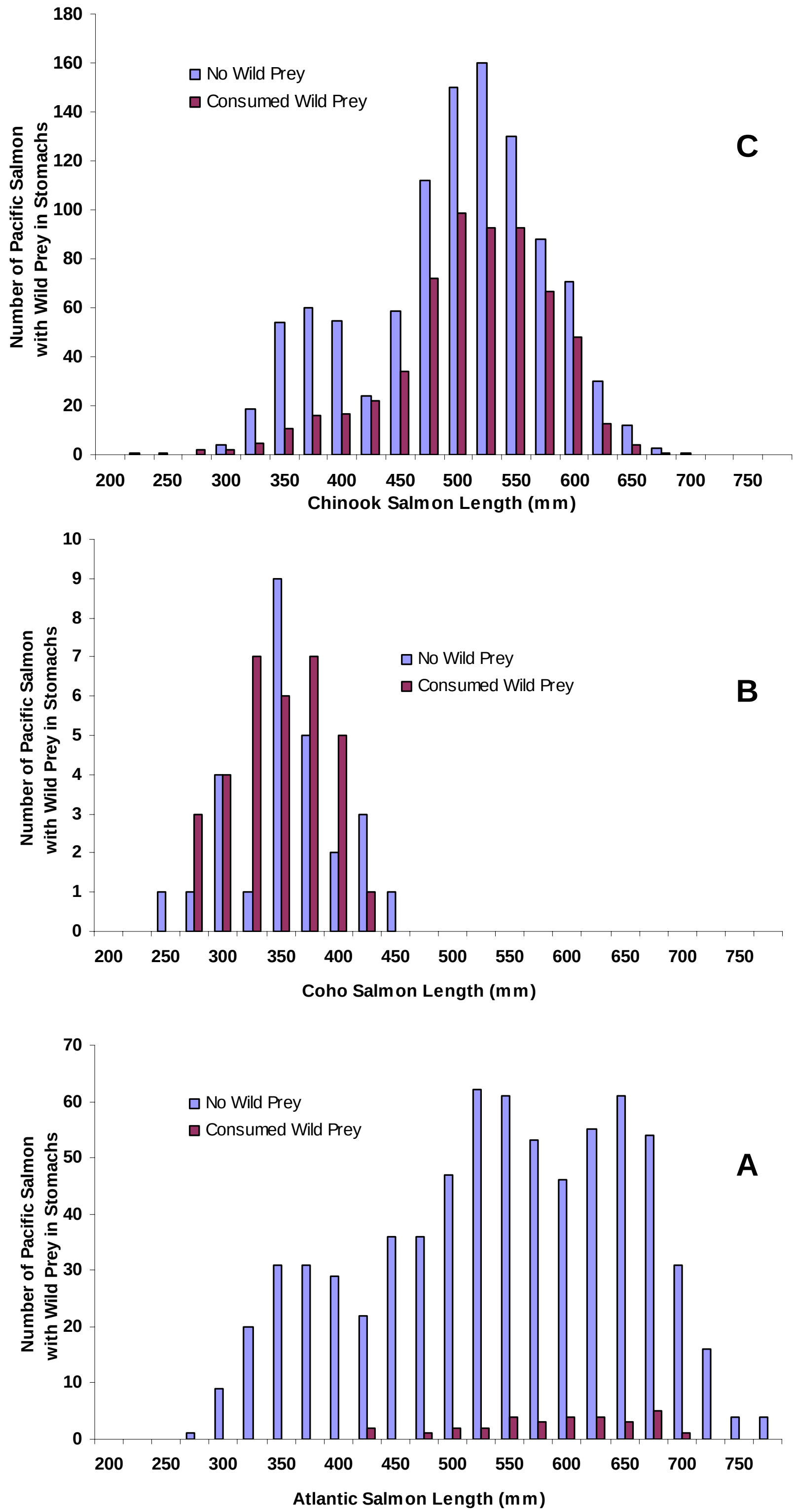

Figure 4: Length frequency distribution of (A) Atlantic, (B) coho and (C) chinook salmon with and without wild prey items identified in stomachs samples. Data derived from Gillis et al. 1989 (chinook and coho) and Hay et al. 2004 (Atlantic).

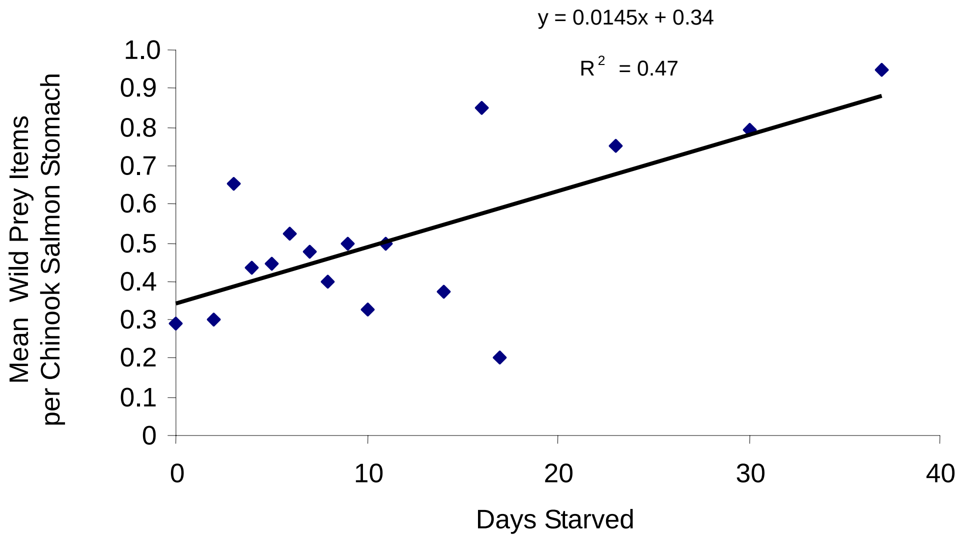

Figure 5: Regression analysis ($p<0.01$) of mean wild prey items consumed by cage-reared chinook salmon associated with number of days starved prior to harvesting.