

Canadian Commercial Catches and Escapements of Chinook and Coho Salmon Separated into Hatchery- and Wild-Origin Fish

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Abstract

This report presents preliminary estimates of Canadian salmon abundance time series partitioned into hatchery- and wild-origin fish for return years 1975-2012. We present a novel coded-wire tag based method to estimate the numbers of hatchery-origin coho and Chinook salmon in the Canadian catch, a method developed that also identifies the jurisdiction of origin of hatchery fish. Escapements were also estimated and partitioned into hatchery- and wild-origin coho and Chinook salmon using spawner escapement data, hatchery-origin escapement estimates, and hatchery release numbers. Missing data in time series of annual escapement were imputed using a method of infilling expected values in contingency tables. When taking into account the entire time series for each species, wild fish were always more abundant than hatchery fish in both catch and escapement, except for Chinook catches off the West Coast of Vancouver Island. Catches of migrating U.S. hatchery fish resulted in higher proportions of hatchery fish in the catch than escapements for coho on the West Coast Vancouver Island and Chinook throughout British Columbia. We are currently making refinements to the methods that may result in changes to the preliminary results presented here.

Introduction

At the 21st annual NPAFC Meeting in 2013, the Stock Assessment Working Group reported on progress partitioning historical salmon abundance time series into hatchery and wild fish (NPAFC 2013). Canada indicated that generation of hatchery/wild abundance time series by the 2014 meeting was achievable. This report presents our progress over the past year.

Although juvenile production from salmon hatcheries in the Pacific Rim began as early as the 1870s in some regions, it was not until the 1950s and 1960s that improved survival due to innovations in feeding, disease control and rearing resulted in substantial contributions of hatchery-origin fish to fisheries (Naish et al. 2008). The total numbers of hatchery releases to the North Pacific were 858 million in 1970, climbed gradually to more than 5 billion in 1990, and have remained roughly constant at that number from then until 2011 (Irvine et al. 2012).

In Canada, salmonid enhancement activities were occurring by the 1960s but initiation of the Salmonid Enhancement Program (SEP) in 1977 in British Columbia (BC) resulted in oversight of most enhancement activities by Canada's Department of Fisheries and Oceans. The objective of SEP at its initiation was primarily to rebuild depressed stocks and to increase catch through the expanded use of enhancement technology (MacKinlay et al. 2004). Total releases peaked in the early 1990s at almost 600 million fish, with chum and sockeye constituting the majority of releases. Numbers subsequently declined and then stabilized at about 300 million fish released annually in recent years (Irvine et al. 2013).

Researchers have partitioned Pacific salmon abundance time series into relative proportions of hatchery- and wild-origin fish for various species, areas, and populations. In a recent review of Japanese research, Morita (2014) estimated the relative contribution of hatchery and wild chum, pink and masu salmon to total production (catch plus escapement) in the Hokkaido region of Japan by determining the ratio of thermal otolith-marked and adipose-fin clipped fish in returning spawners and otolith-marked fish in the commercial catch, as well as using population models to estimate the contribution of hatchery salmon to catch for some populations. Zaporozhets and Zaporozhets (2012) estimated the proportion of hatchery-origin chum salmon returning to the Russian Paratunka River by using scale structure to identify hatchery- and wild-origin fish. Other regional studies partition catch only into hatchery and wild. The Alaska Department of Fish and Game publishes an annual report of their enhancement program (e.g., Vercesi 2014) that estimates the Alaska-origin hatchery and wild proportions of Chinook, sockeye, coho, pink and chum salmon in their commercial fisheries. In BC, MacKinlay et al. (2004) estimated the relative contribution of hatchery-origin coho, Chinook and chum to Canadian catches (commercial plus marine recreational) in southern BC, using recovery of coded-wire tags (CWTs) in the Canadian catch of coho and Chinook, and of CWTs and adipose fin clips for chum catch. Commercial catch totals were estimated from sales slip records, and recreational catches via creel surveys combined with estimated numbers of sport fishing boats.

Others have partitioned Pacific salmon abundances into relative proportions of hatchery- and wild-origin fish for the entire North Pacific. Eggers (2009) estimated total biomass by species for sockeye, pink and chum salmon in the North Pacific by run reconstructions using age-structured models based on available commercial catch, escapement and hatchery release data. Kaeriyama et al. (2009) also partitioned sockeye, pink and chum for the North Pacific into hatchery- and wild-origin fish, using modified expansion factors from D. Eggers (unpublished data). Run size estimates for particular hatchery populations were used to partition total run size estimates into hatchery and wild components. Ruggerone et al. (2010) used reported total abundance (catch plus escapement for chum, pink, and sockeye salmon) where possible, partitioned into hatchery- and wild-origin, and a variety of other methods to estimate catch and escapement where more direct estimates of total abundance data were unavailable.

We assume that the Ruggerone et al. (2010) estimates for pink, chum and sockeye are appropriate, and the purpose of the present work is to supplement those data with abundance estimates of Chinook and coho salmon partitioned into wild- and hatchery-origin fish. We report on the retained commercial catch and spawning escapement of Canadian populations for three large regions of BC (Fig. 1). The methodology we use to estimate the hatchery-origin contribution to commercial fishery catches can be extended at least to Alaska and the coastal contiguous United States.

In Canada, wild salmon are defined in the Wild Salmon Policy as fish that “have spent their entire life cycle in the wild and originate from parents that were also produced by natural spawning and continuously lived in the wild” (DFO 2005). In this study, hatchery-origin fish included only first-generation hatchery fish that were produced in a hatchery; offspring of naturally-spawning hatchery-origin fish were included with wild salmon.

Methods

Commercial Catch

We apply a new method to partition commercial Chinook and coho catch into wild- and hatchery-origin fish that uses hatchery release and recovery data from the North American coastwide coded-wire tagging and recapture program. The binary coded-wire tag (CWT) is a small piece of magnetized wire, stamped with either a binary or numerical code that is implanted in the nasal cartilage of juvenile salmonids. A CWT allows release groups, with each fish in the group carrying the same code, to be identified to release location and by year of release when tagged fish are subsequently recovered. In 1977, U.S. and Canadian fisheries managers agreed to reserve the adipose-fin clip as an externally visible mark to indicate the presence of a CWT (Nandor et al. 2010). Beginning in brood year 1995 in the U.S. and 1996 in Canada for coho salmon, adipose fin clips have been used to identify hatchery-origin fish, whether or not they have been implanted with a CWT (Pacific Salmon Commission 2013). This practice was begun for Chinook salmon released from U.S. hatcheries in 1998 but Canada has not adopted this practice for this species. For CWT-associated release groups of juvenile salmon, a known number have CWTs, and non-tagged fish in the release may be marked with the adipose fin clip (coho and Chinook released from U.S. hatcheries; coho released from BC hatcheries) or are not marked externally (Chinook salmon released from BC hatcheries). For unassociated release groups, most fish are marked by removal of their adipose fin, but there are no associated CWTs.

Our method (Fig. 2) directly estimated numbers of hatchery- origin coho and Chinook salmon in commercial catches using data from the DFO CWT mark-recovery program (MRP) database. Our CWT-based approach is applied to a single fishery, e.g., the BC Chinook Northern Troll fishery, and hatchery-origin catches can then be summed for larger regions. In the MRP database, Canadian catches are reported by Catch Region; each Catch Region is defined as a bounded area comprised of a number of Pacific Fishery Management Areas (PFMAs, Table 1) and a specific gear type. Small fisheries were excluded from the analysis due to concerns about uncertainties associated with very small recovery sample sizes. The hatchery release jurisdictions involved were Alaska, BC-Yukon, and the Southern Pacific coastal United States. Basins and regions are as defined by the Pacific Salmon Commission and are the ones that are recorded in the MRP and Regional Mark Information System (RMIS) databases. In BC, there are 7 regions, each comprised of 3-4 basins, except for the Haida Gwaii region, which is comprised of one basin. The Yukon jurisdiction is made up of two regions, each having a single basin. Although we combined BC and Yukon into one jurisdiction for the purposes of the analysis, hatchery production in the Yukon is minimal.

Each recovered CWT has an associated individual release code; characteristics of that individual hatchery release batch are available from the MRP (to DFO staff) or from the public access RMIS database where information such as numbers of fish that were adipose fin-clipped (marked) and numbers of fish that had CWTs (tagged) are reported annually by all agencies in the Pacific Northwest applying CWTs. Because not all Coho and Chinook salmon released from hatcheries have been implanted with a CWT or are associated to a CWT release group, numbers of fish with CWTs were expanded to account for unassociated releases in order to generate estimates by basin, region, and jurisdiction (Fig. 2). The total number of hatchery-origin fish in a catch was calculated as the sum of the CWT-associated and unassociated hatchery-origin portion of the catch (contact authors for details on methods). Total catch was estimated by summing the catches for the individual strata making up the included Catch Regions as recorded in the MRP database. Estimates of wild numbers of fish were made by subtracting the estimate of hatchery-origin catch numbers from the total catch.

Because only fisheries with substantial numbers of tag recoveries were included in our analysis, a potential concern was whether we were missing significant components of the catch. To evaluate this, we compared the subset of the total (hatchery plus wild) MRP catches of coho and Chinook that were used in our estimation of hatchery-origin catch with those published in Irvine et al. (2012) (Figs. 3 and 4).

Spawning Escapement

Escapement time series for BC streams with coho and Chinook salmon were downloaded from the Department of Fisheries and Oceans Canada (DFO) salmon escapement database (NuSEDS, **Error! Hyperlink reference not valid.** 6 November 2013 for coho and 20 November 2013 for Chinook; Fig. 5, left hand side). An algorithm provided by Brown (1974) was used to impute missing escapement values. The infilling approach did not work on streams with intermittent spawner estimates; these data were not used in the analysis. This was not considered serious, however, because these streams tended to have low escapements. Escapements were aggregated into watersheds draining into the three marine catch regions (Fig. 1). Recent estimates may be relatively imprecise due to generally reduced effort estimating spawner numbers.

Two separate methods were used to determine the proportions of the spawner escapements comprised of fish of hatchery origin (Fig. 5). In method 1, for each species we obtained estimated proportions of hatchery-origin escapements for hatchery streams from enhancement staff (David Willis, DFO, Vancouver, BC). Because these values did not account for hatchery-origin fish returning to non-hatchery streams, method 1 estimates are presumably biased low. For example, Chinook salmon from Robertson Creek have been documented in various streams along the West Coast Vancouver Island (WCVI) (e.g., Candy et al. 2009). The time series of proportions were incomplete, so we evaluated hatchery release data from the MRP database (retrieved 22 November 2013) to identify gaps in the escapement time series that were not expected based on release data and estimated hatchery proportions in the escapement. In those cases, we used linear regression between the two datasets (i.e., release numbers and proportion hatchery-origin escapement) to infill the hatchery-origin escapement proportion by stream. Proportions of hatchery-origin escapement were then multiplied by total escapement estimates from the infilled escapement time series to generate hatchery-origin escapement abundance. Estimates of hatchery proportions were incomplete for some coho and Chinook streams late in the time series, resulting in underestimates of hatchery contributions.

For coho, in addition to the estimation of total escapement as detailed above, we also used a hatchery-release based method (method 2) to generate a separate time series of hatchery-origin escapements (Fig. 5, right hand side). We multiplied region-specific (i.e. North Coast, South Coast, WCVI) smolt and fry survival estimates (fry survival assumed to be 10% of smolt survival) by hatchery release numbers to

estimate hatchery-origin returns (i.e. fish recruiting to fisheries). We then applied region-specific exploitation estimates to estimate the numbers of hatchery-origin fish in the escapement to that region.

Hatchery-origin escapements were subtracted from total escapements to estimate wild escapements (Fig. 5).

Results and discussion

Note that all results are preliminary and may change.

Coho

A comparison of the catch as recorded in Irvine et al. (2012) and the catches that were used for the CWT-based catch analysis were virtually identical for coho, indicating that the majority of the catch was used in that analysis (Fig. 3).

In the late 1990s, commercial coho fisheries in BC were severely curtailed due to conservation concerns. In the North Coast region, some fisheries have since reopened (Fig. 6A). Coho catch was almost entirely of wild origin, with a small proportion of hatchery-origin catch coming primarily from Alaska and BC. Wild fish also dominated escapement in this region according to both methods (Figs. 6B and C). As mentioned previously, escapement estimates in recent years may be biased low.

Off WCVI, the commercial catch time series showed reduction of harvest in 1997 to very low numbers (Fig. 7A), and escapement improved at this time, presumably at least partly in response to the much-reduced commercial exploitation (Figs. 7B and C). Hatchery-origin coho from the Southern U.S. dominated the hatchery contribution to the catch, with a substantial contribution from BC hatcheries as well (Fig. 7A). Wild fish made up more than half of the catch, but it was not possible to determine their jurisdiction of origin using our methods. Method 2 estimated a higher number of hatchery-origin spawners than method 1.

Similarly to the other two regions, coho catches in the South Coast were reduced to near zero in the mid-1990s as a result of fishery closures. Our estimates of hatchery-origin catch in the South Coast region suggested that coho from the Southern U.S. were at least as important as Canadian hatchery coho in those fisheries (Fig. 8A). Catch decreased during the time series. Wild fish dominated the escapement, and the estimate of hatchery spawner numbers was greatest according to method 2 (Figs. 8B and C).

Chinook

As found for coho, a comparison of the catch as recorded in Irvine et al. (2012) and the catches that were used for the CWT-based catch analysis were similar for Chinook, indicating that the majority of the catch was used in that analysis (Fig. 4).

In the North Coast region, total commercial catch of Chinook declined during the time series, with wild fish dominating the catch (Fig. 9A). Of the hatchery-origin portion, at least half was of Southern U.S. origin in most years, with most of the rest from BC, and very small numbers of Alaskan hatchery fish. Virtually all the escapement was wild, and abundance seemed to increase during this time period (Fig. 9B). Method 1 was based on the hatchery-origin escapements to the main hatchery streams. Although there are hatcheries in the North Coast region that produce Chinook, they were under-represented in our escapement time series, resulting in the hatchery-origin component in the time series being underestimated.

Off WCVI, catches declined until the mid-1990s and have remained relatively low since then (Fig. 10A). Hatchery fish tended to constitute the majority of the catch, and most of these originated in the Southern U.S. The very small wild catch proportion in 1979 was due to an uncharacteristically large (compared to other years) catch estimate of hatchery fish originating from the Southern U.S. that year; we are investigating this value. The validity of the relatively low Canadian hatchery contribution in recent years is also being investigated. Escapements appeared to be predominantly wild, and these showed a generally increasing trend until the early 1990s and variable numbers since then (Fig. 10B). However, we note that the recent proportions of hatchery-origin escapements to the Conuma and Nitinat rivers were not estimated, resulting in negative bias in the proportion of hatchery fish escaping to WCVI streams.

In the South Coast region, commercial Chinook fisheries were shut down in the mid-1990s due to conservation concerns and have not reopened (Fig. 11A). Catches were dominated by wild-origin fish until the late 1980s when hatchery fish began to make up approximately half of the catch. Of the hatchery-origin portion of the catch, Chinook from the Southern U.S. tended to be more numerous than Canadian-origin hatchery fish. Escapements gradually increased over the time period with wild-origin fish dominating (Fig. 11B), but similar to other regions, the hatchery contribution to the escapement time series was likely biased low due to incomplete data.

Summary

- When taking into account the entire time series for each species, wild fish were always more abundant than hatchery fish in both catch and escapement, except for Chinook catches off WCVI
- Catches of migrating U.S. hatchery fish resulted in higher proportions of hatchery fish in the catch than in the escapements for coho (WCVI) and Chinook (all three regions).
- Method 2 estimated a larger proportion of hatchery-origin fish in the escapement of coho in all regions than method 1, perhaps in part because method 1 did not account for hatchery-origin strays.

Potential next steps

The methods and results documented here are preliminary and are being revised and updated. There are a number of directions we are currently exploring as possible extensions of this work:

- Extend CWT-based partitioning of commercial catch into hatchery and wild to Alaskan and Southern U.S. fisheries.
- Refine the CWT-based approach in various ways such as adding estimates of uncertainty.
- Because of data quality issues with the regional escapement database (NuSeds), investigate the utility of indicator stream data sets as an alternate way of proportioning spawner numbers into hatchery- and wild-origin fish.
- Convert catch and escapement estimates to total returns or total species biomass.
- Incorporate recreational catches into catch estimates.
- Document methods and results in the primary literature.

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Table 1. Assignment of Pacific Fisheries Management Areas (PFMAs) to the three regions of BC shown in Figure 1.

North Coast	WCVI	South Coast
1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 101, 102, 103, 104, 105, 106, 107, 108, 109, 110, 130, 142	21, 22, 23, 24, 25, 26, 27, 121, 123, 124, 125, 126, 127	11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 28, 29, 111

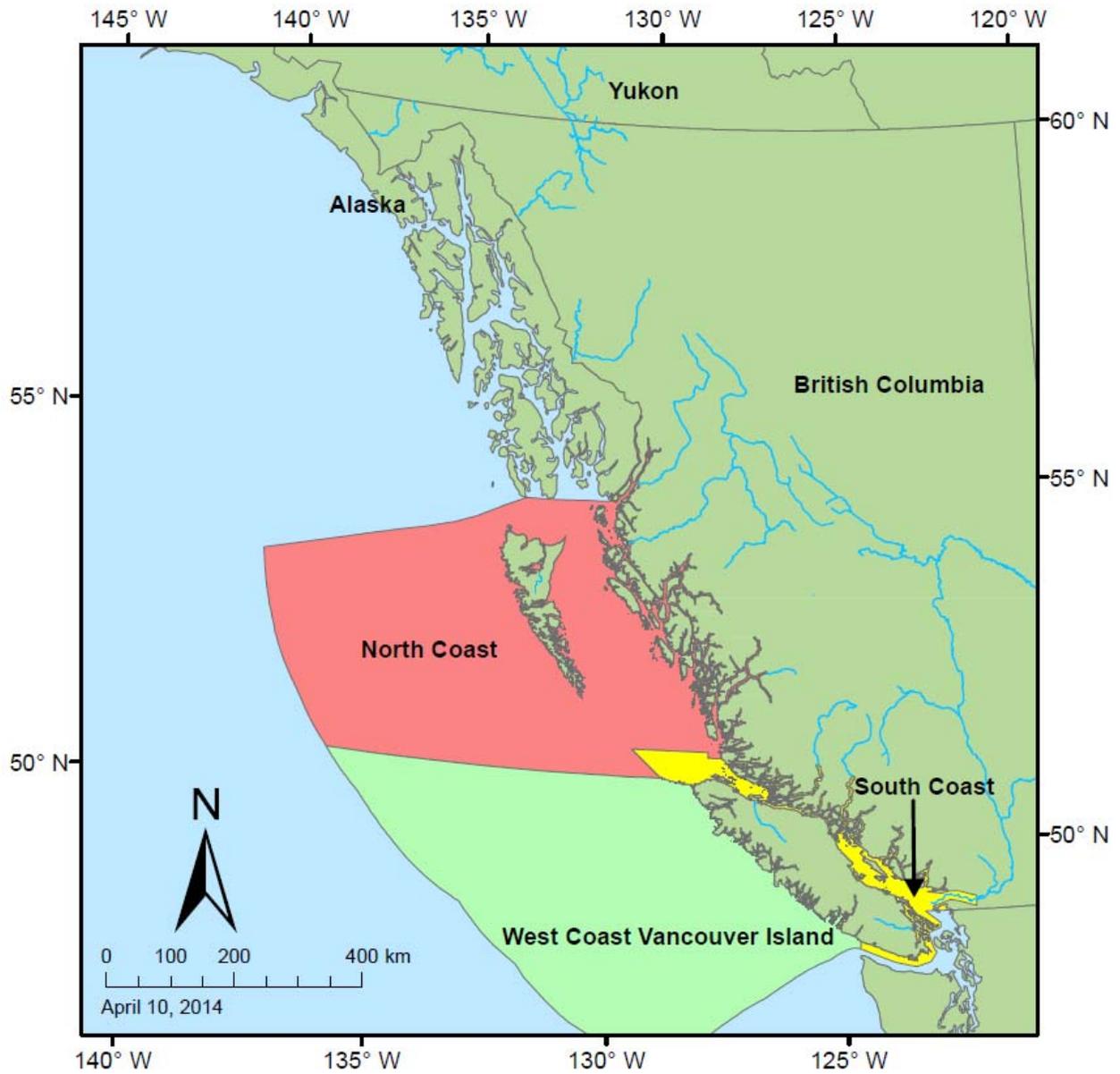


Figure 1. Map of BC showing three major catch regions. For a detailed description of the Pacific Fisheries Management Areas included in each region, see Table 1.

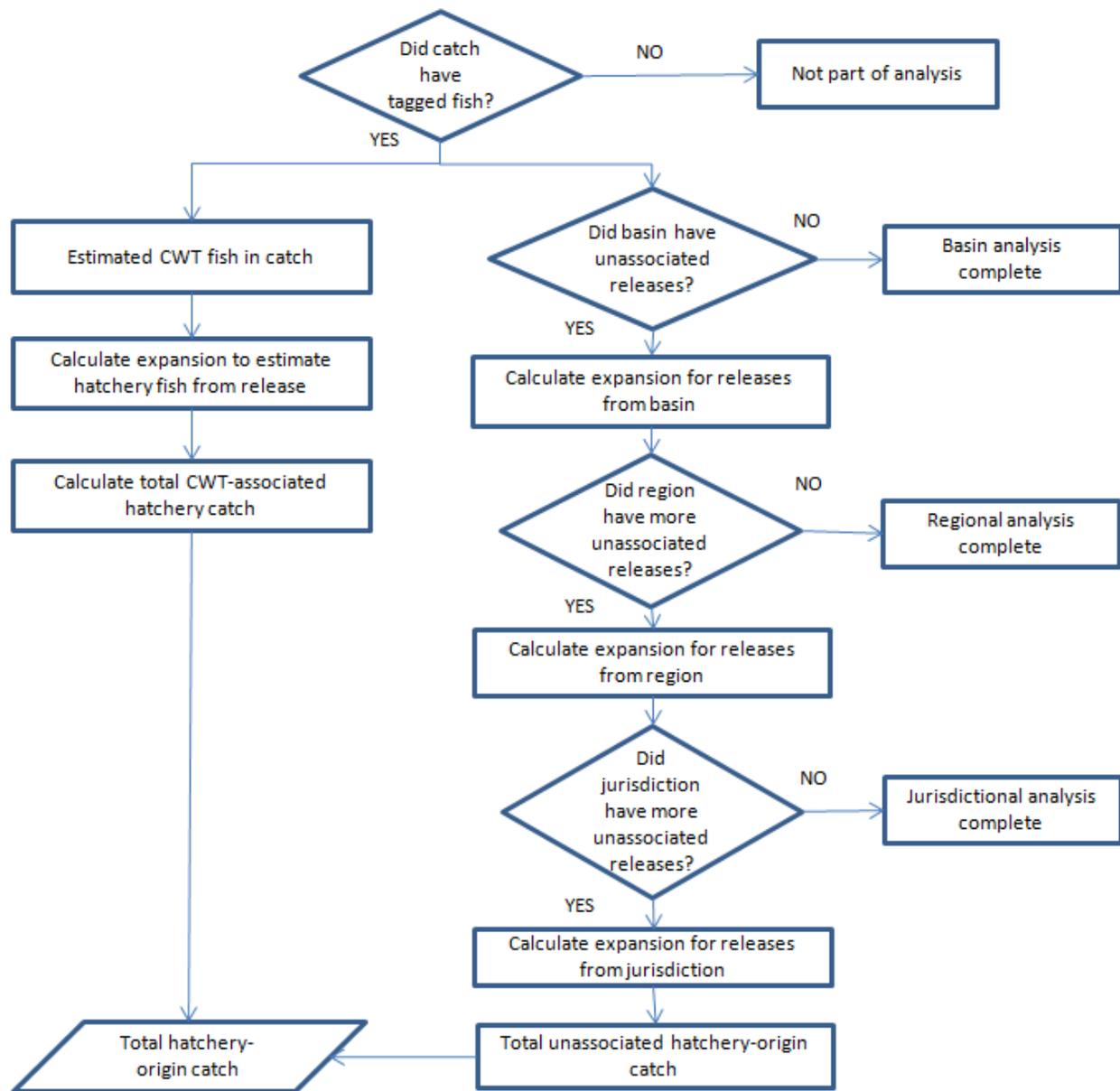


Figure 2. Flowchart showing the main components of the novel method for estimating numbers of hatchery-origin fish in the catch. Wild catch was estimated by subtracting hatchery-origin catch from total catch (see Methods for details).

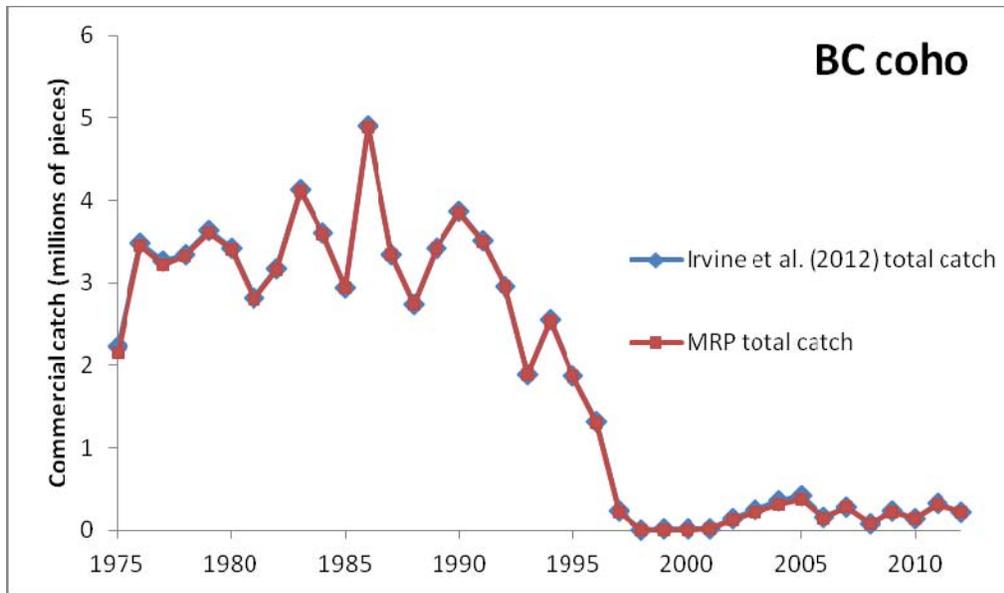


Figure 3. Comparison between commercial coho catch in BC according to Irvine et al. (2012), and the summed total catch of the main troll and net fisheries used to estimate hatchery-origin numbers in the CWT-based approach. Return years are displayed in this and subsequent figures.

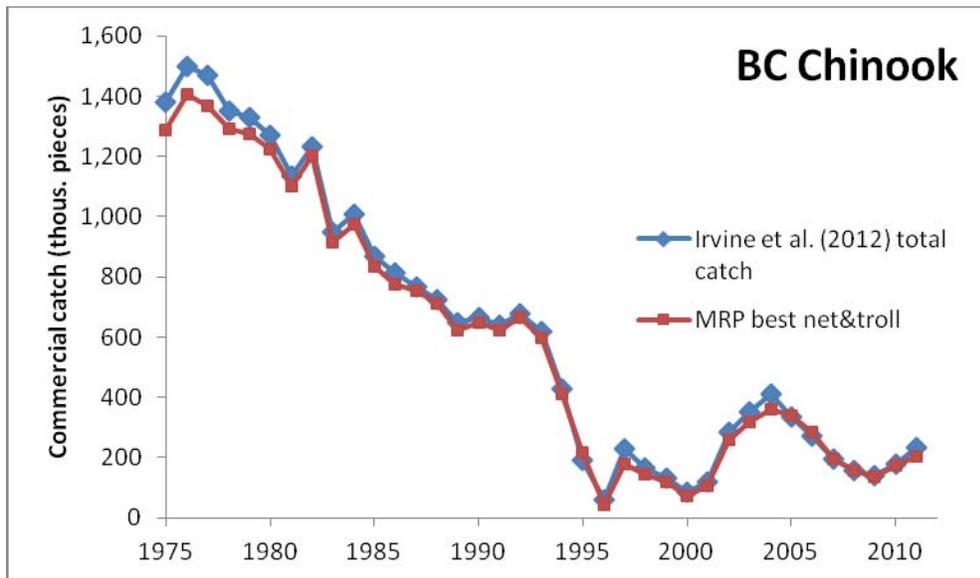


Figure 4. Comparison between commercial Chinook catch in BC according to Irvine et al. (2012), and the summed total catch of the main troll and net fisheries used to estimate hatchery-origin numbers in the CWT-based approach.

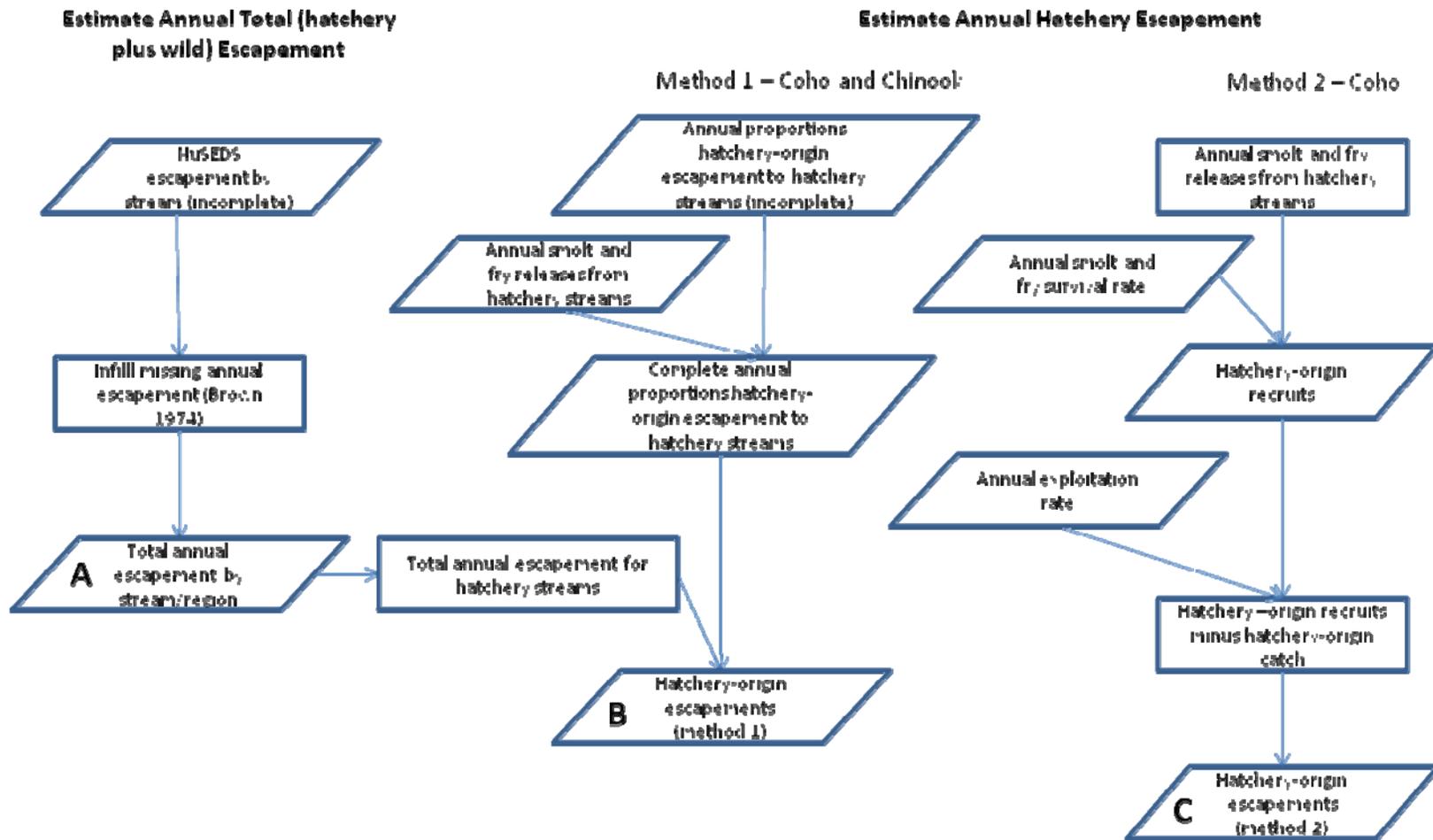


Figure 5. Flowchart showing methods used to determine hatchery- and wild-origin proportions in the coho and Chinook escapement. Wild escapement was estimated by A minus B and A minus C using hatchery methods 1 and 2 escapements respectively.

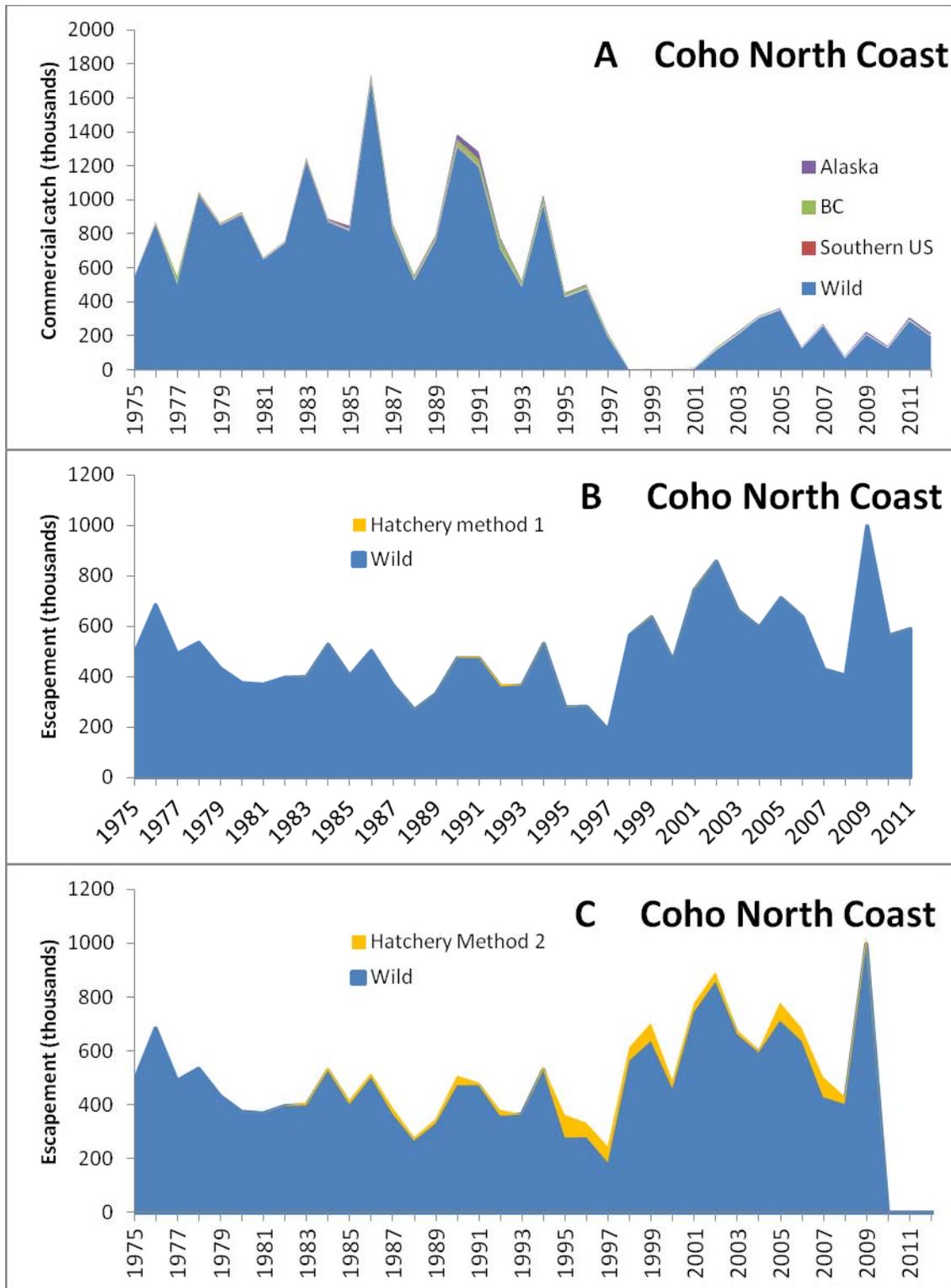


Figure 6. Proportion of wild (blue) and hatchery-origin coho in the commercial catch (A) and escapement (B and C) in the North Coast region, showing jurisdiction of origin of hatchery fish by return year in (A). Hatchery components in (B) and (C) were estimated using methods 1 and 2 respectively.

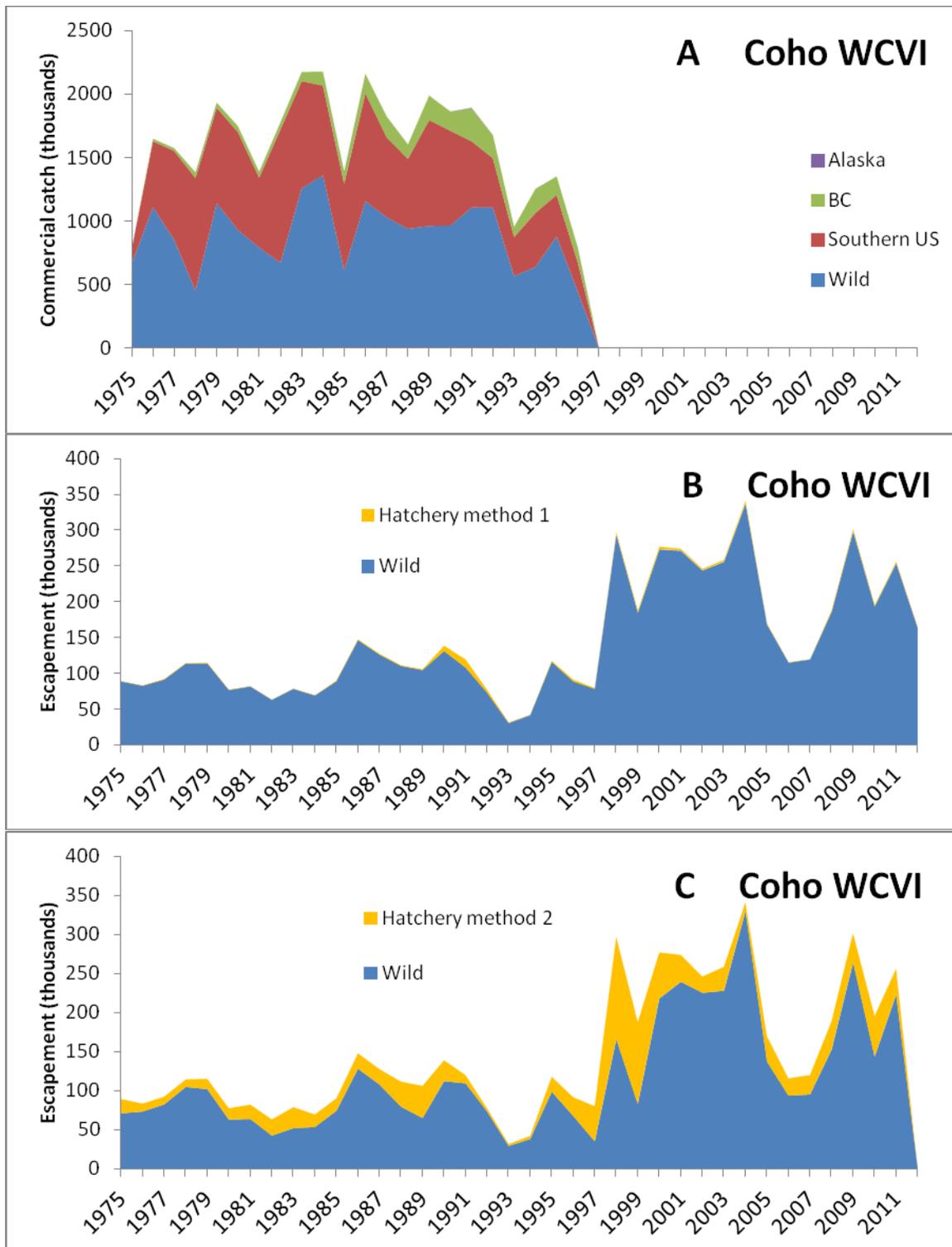


Figure 7. Proportion of wild (blue) and hatchery-origin coho in the commercial catch (A) and escapement (B and C) in the West Coast of Vancouver Island region, showing jurisdiction of origin of hatchery fish by return year in (A). Hatchery components in (B) and (C) were estimated using methods 1 and 2 respectively.

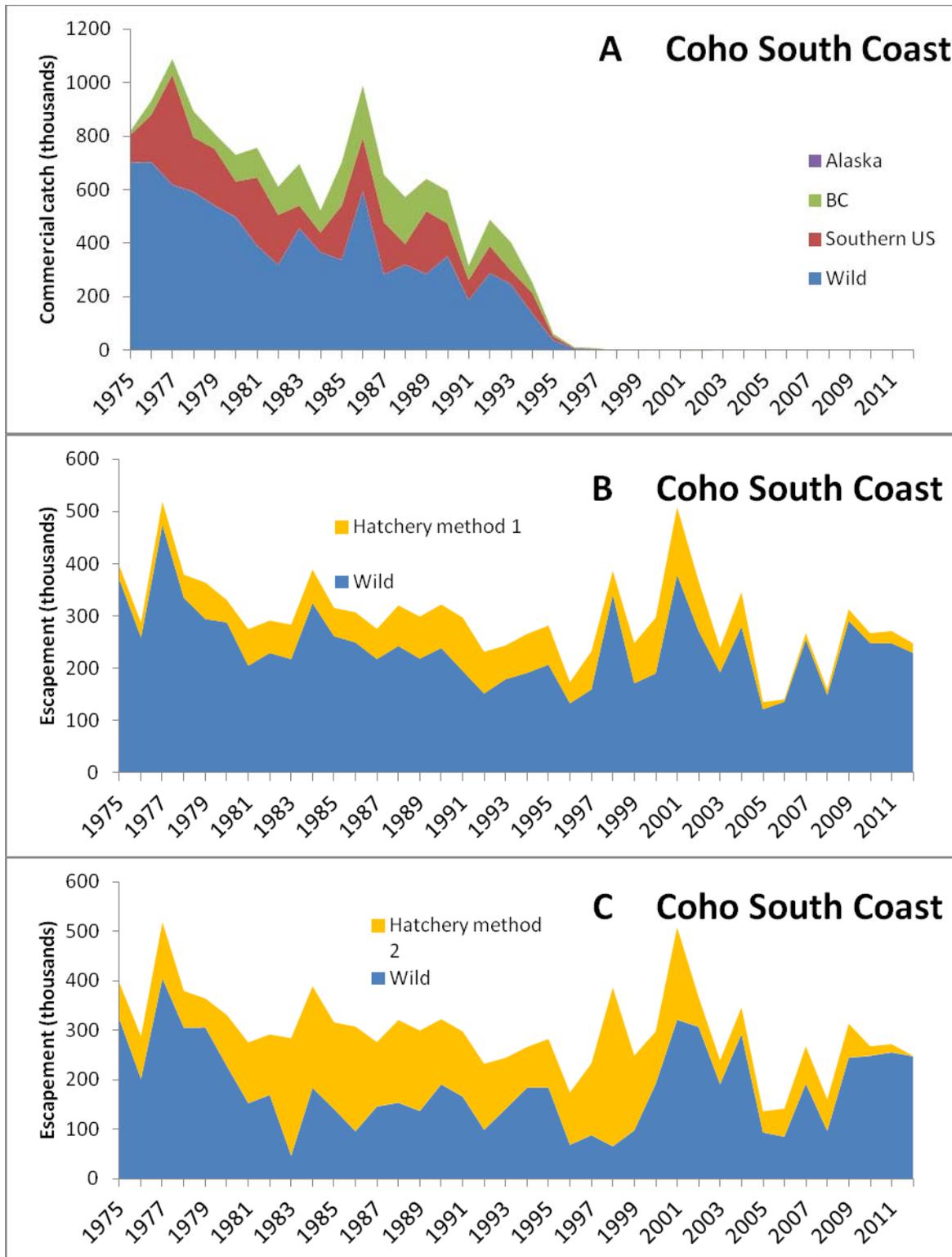


Figure 8. Proportion of wild (blue) and hatchery-origin coho in the commercial catch (A) and escapement (B and C) in the South Coast region, showing jurisdiction of origin of hatchery fish by return year in (A). Hatchery components in (B) and (C) were estimated using methods 1 and 2 respectively.

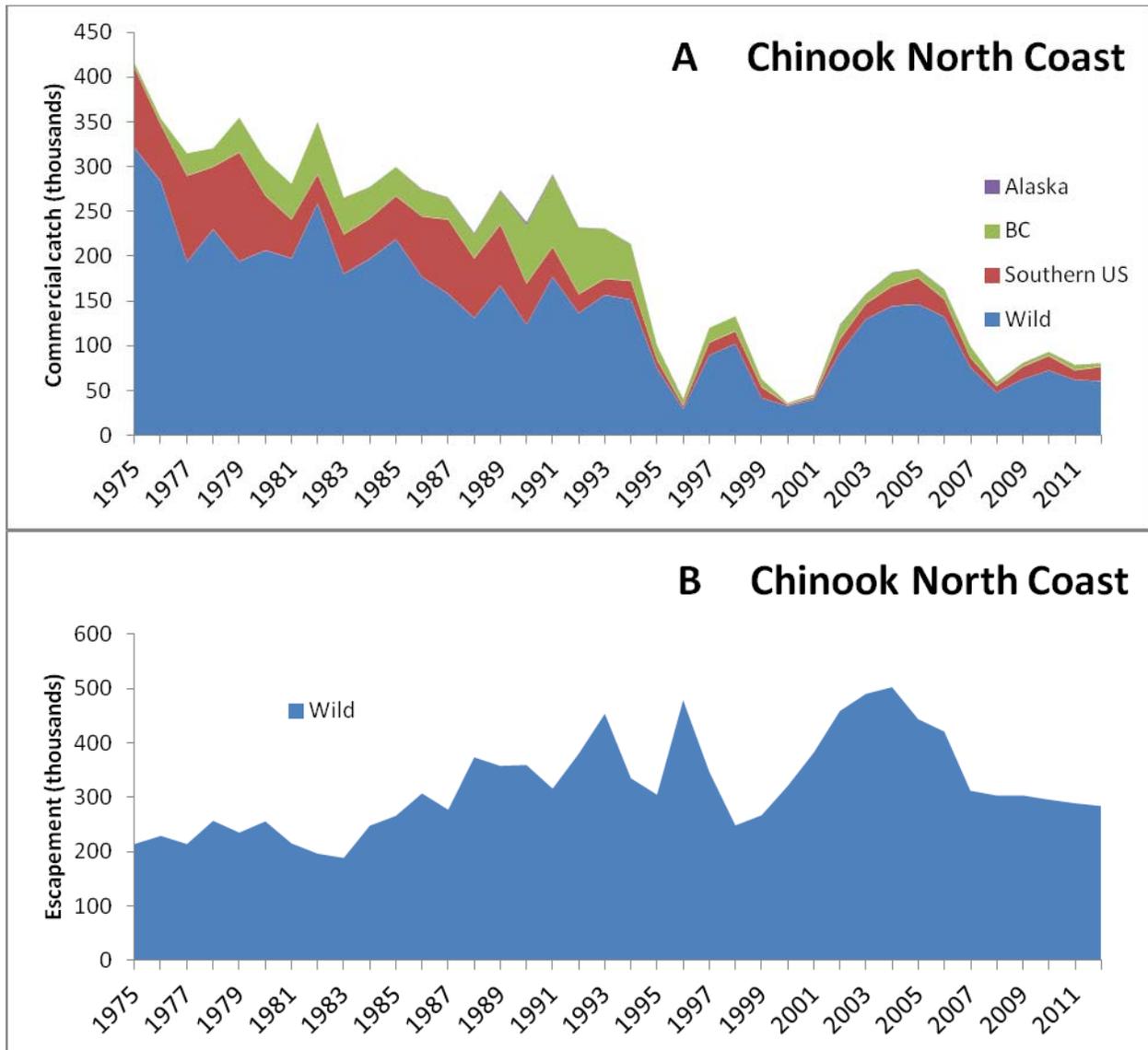


Figure 9. Proportion of wild (blue) and hatchery-origin Chinook in the commercial catch (A) and escapement (B) in the North Coast region, showing jurisdiction of origin of hatchery fish by return year in (A). The hatchery component in (B) was estimated using method 1.

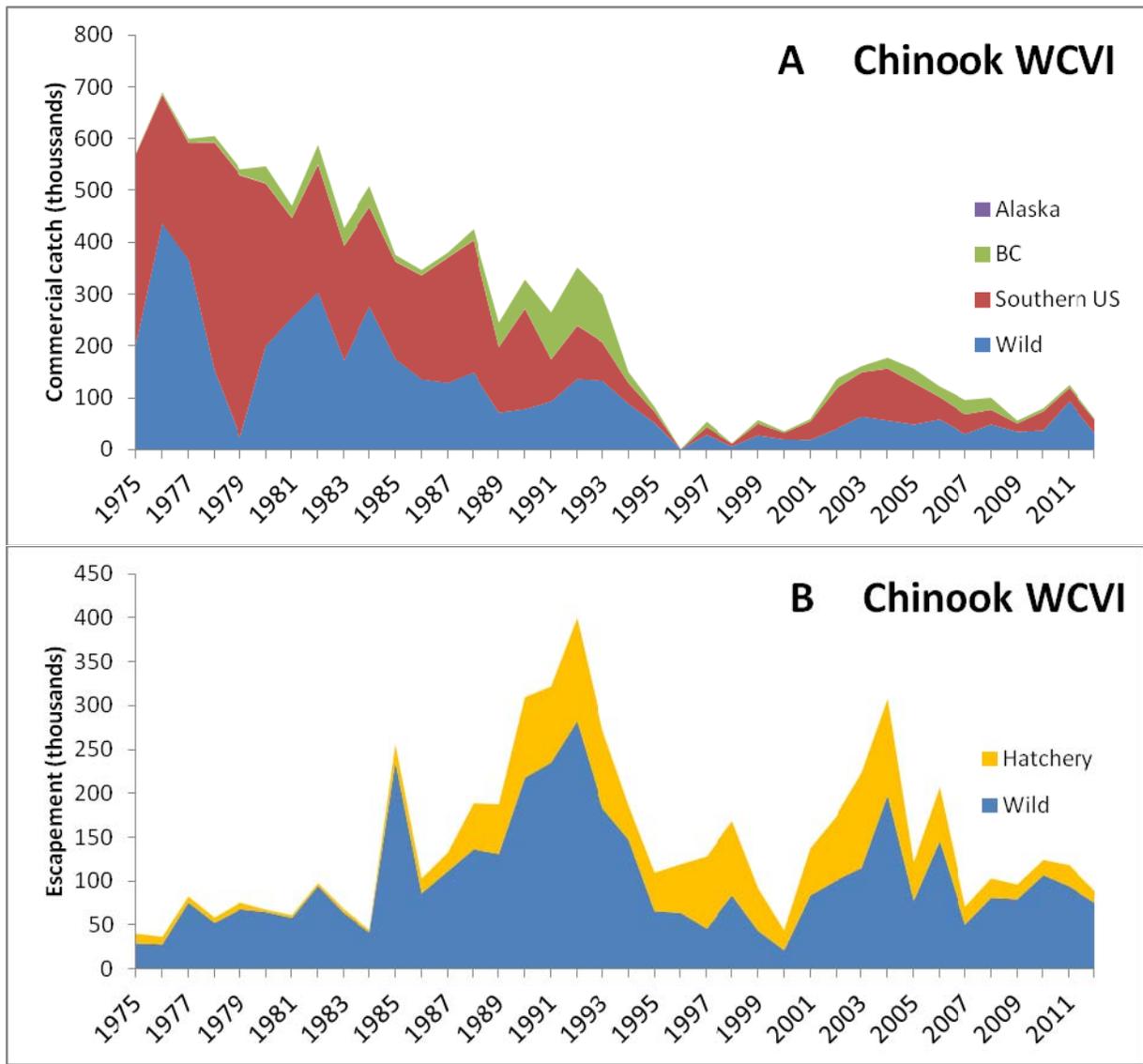


Figure 10. Proportion of wild (blue) and hatchery-origin Chinook in the commercial catch (A) and escapement (B) in the West Coast of Vancouver Island region, showing jurisdiction of origin of hatchery fish by return year in (A). The hatchery component in (B) was estimated using method 1.

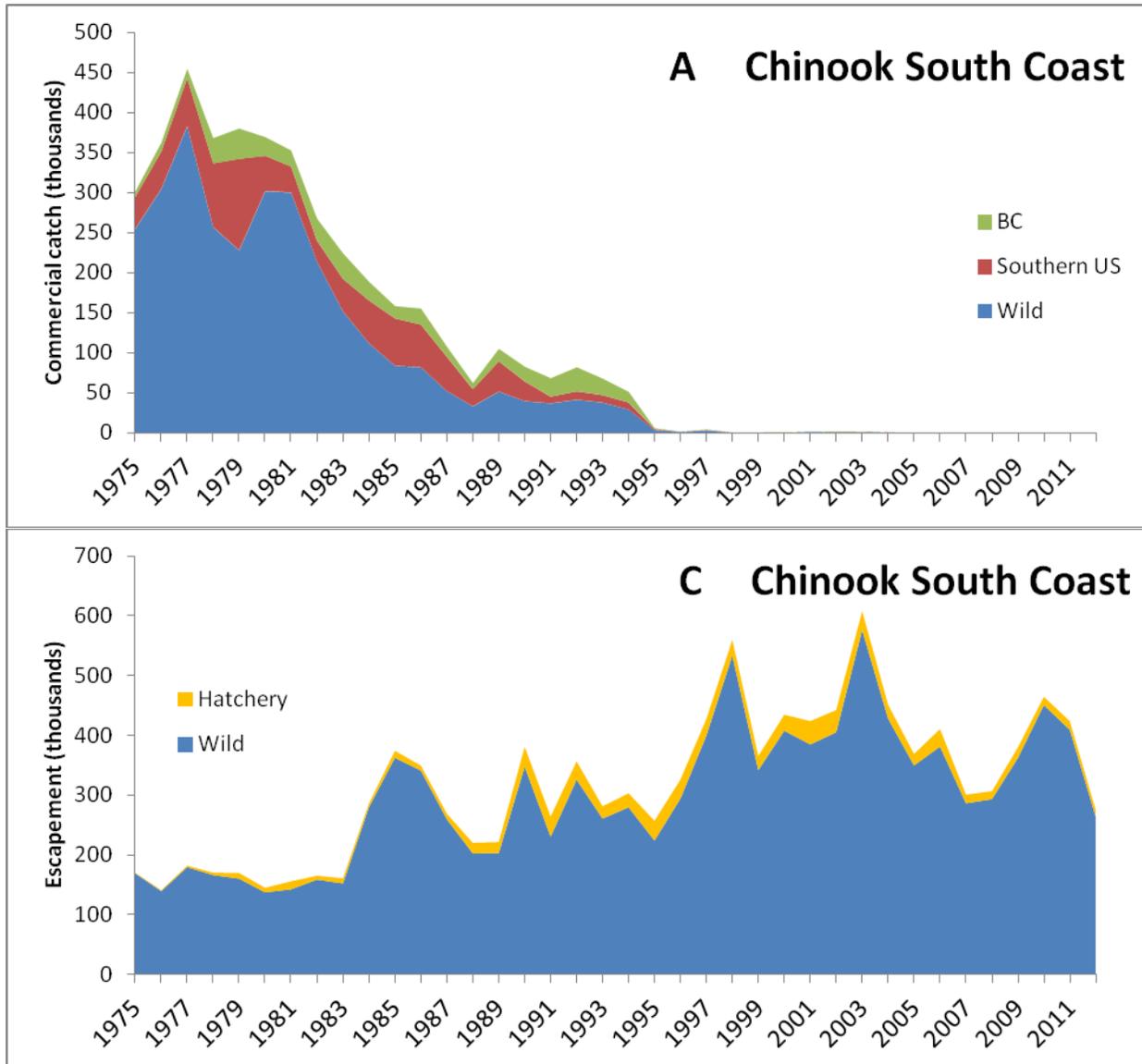


Figure 11. Proportion of wild (blue) and hatchery-origin Chinook in the commercial catch (A) and escapement (B) in the South Coast region, showing jurisdiction of origin of hatchery fish by return year in (A). There were no Alaska-origin hatchery fish estimated for this region. The hatchery component in (B) was estimated using method 1.