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Stock Status of Wild Chum Salmon (*Oncorhynchus keta Walbaum*) Returning to British Columbia's Central Coast and Johnstone and Georgia Straits (excluding the Fraser River)

État du stock de saumon kéta sauvage (*Oncorhynchus keta Walbaum*) retournant vers la Côte Centrale de la Colombie-Britannique et les détroits de Georgia et de Johnstone (à l'exception du fleuve Fraser).

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Abstract

We describe the status of six main chum salmon stock groupings from the Central Coast and the southern non-Fraser Inner Study Area (ISA). The first four correspond to the chum returning to Statistical Areas 7, 8, 9, and 10 and are referred as “northern stocks”. The fifth stock is those fish returning to Area 11 (Seymour Inlet). The sixth stock comprises fish spawning in the ISA (Johnstone and Georgia straits) but excludes fish from the Fraser River. Our overall goal was to assess the status of these stocks and describe how status varied temporally between 1953-2002.

Status was based primarily on trends in escapement as well as a comparison of escapement to reference points. We calculated two reference points based on the long-term median escapement (LTME) that defined three zones (red:≤ 60% LTME, amber:>60 % LTME < escapement < 80%LTME, and green: ≥ 80%LTME). We performed a similar analysis using total run sizes. Status variability within stock groupings was assessed by calculating and comparing relative rates of change in escapement per year for individual streams. Temporal variations in stock status were analysed by evaluating the stock status based on the complete time series and based on data from the last three generations only.

Chum salmon in Areas 7 and 8 were generally in the green zone. While there are no apparent management concerns with these fish, we recommend that Area 7 chum should be monitored closely since total run size appears to have been reduced by ~22% during the last three generations.

We have some concerns for chum returning to Areas 9-11, and north-eastern Johnstone Strait (EJST). Although long and short-term trends in escapements to Area 9 were not negative, the median escapement and total run size during the last three generations were in the amber zone. Escapements in Area 10 showed a negative trend during the last three generations, although the median escapement was in the green zone. Inefficient escapement surveys during the last 3 generations might be responsible for this apparent decline in escapement. Escapements in Area 11 declined over time, and the median of the last three generations was in the amber zone while total run size was in the green zone.

There was significant variability in patterns for the southern stocks. Stocks on both sides of Johnstone Strait have declined recently. The decline of the Eastern stock was the most drastic of all; recent escapements and total run sizes were in the red zones, both being reduced to less than half their long-term median.

Interestingly, chum in North West Georgia Strait (NWGS) increased during the last three generations; escapements and total run size generally were in the green zone. This increase may be related to changing fishery practices on enhanced chum returning to this area. Chum returning to NEGS, SWGS, and SEGS had similar patterns to each other. All Georgia Strait stocks increased during the complete time series and during the last generations and were in the green zone.

Résumé

Nous décrivons l'état de six importants stocks de saumons keta de la Côte Centrale et de la Côte Sud soit dans les détroits de Johnstone et de Georgia de la Colombie Britannique. Les quatre premiers stocks correspondent au saumon keta retournant dans les zones statistiques de pêche 7, 8, 9, et 10, on les appellera les "stocks nordiques". Le cinquième stock comprend les poissons retournant dans la zone 11 (Seymour Inlet). Le sixième stock comprend les géniteurs qui fraient dans les rivières se déversant dans les détroits de Johnstone et de Georgia, excluant ceux de la Rivière Fraser, ces derniers seront appelés les "stocks du sud".

Notre but est d'évaluer l'état de ces stocks et de décrire les variations temporelles de leur état. Cette évaluation est basée principalement sur la tendance des géniteurs ainsi qu'une comparaison du nombre de géniteurs à des points de référence. Nous avons calculé deux points de référence basés sur la médiane des géniteurs à long terme (LTME) laquelle définit trois zones (rouge : ≤ 60% LTME, jaune: >60 % LTME < géniteurs <80%LTME, et vert : ≥ 80%LTME). Nous effectuons une analyse similaire en utilisant la taille du stock.

La variabilité de l'état à l'intérieur des stocks a été évaluée en calculant et comparant les taux relatifs de changement du nombre de géniteurs par année au niveau des ruisseaux. Nous avons évalué les variations de l'état de chacun des stocks sur la série temporelle au complet de même que sur les données des trois dernières générations. Les saumons keta des zones 7 et 8 sont généralement dans la zone verte. Même si l'état du stock dans la zone 7 ne présente pas de problème de gestion, nous recommandons que ce stock soit suivi de près étant donné que la taille du stock a diminué de 22% au cours des trois dernières générations.

Nous avons certains soucis en ce qui à trait aux saumons keta qui retournent dans les zones 9-11 ainsi que dans le nord-est du détroit de Johnstone (EJST). Quoique la tendance à court et à long terme des géniteurs de la zone 9 ne soit pas négative, la médiane des géniteurs et de la taille du stock au cours des trois dernières générations était dans la zone jaune. Les géniteurs de la zone 10 avaient une tendance négative au cours des dernières trois générations, même si la médiane des géniteurs au cours de cette période était dans la zone verte. Ce déclin apparent est peut-être dû à un relevé moins efficace des géniteurs des cours d'eaux au cours des 3 dernières générations. Les géniteurs de la zone 11 ont diminué et la médiane au cours des 3 dernières générations était dans la zone jaune alors que la taille du stock était dans la zone verte.

Il y a une variabilité importante dans l'état des stocks du sud. Les stocks des deux côtés du détroit de Johnstone ont diminué récemment. Le déclin du stock de la Côte Est (EJST) était cependant le plus drastique de tous, les géniteurs et la taille du stock étaient dans la zone rouge, tous deux à moins de 50% de leur médiane à long terme.

D'autre part, il est intéressant de noter que le saumon keta dans le nord ouest du Détroit de Georgia (NWGS) a augmenté au cours des 3 dernières générations; alors que les géniteurs et la taille du stock étaient généralement dans la zone verte. Cette augmentation est peut-être due aux changements des pratiques de gestion des saumons d'élevages retournant dans cette zone. Les saumons retournant à NEGS, SWGS, et SEGS avaient des tendances similaires. Tous les stocks du détroit de Georgia ont montré une augmentation tout au cours de la série temporelle ainsi qu'au cours des trois dernières generations.

1 Introduction

Chum salmon (*Oncorhynchus keta* Walbaum), the most widely distributed of the Pacific salmon, make up to 50% of the biomass of salmon in the North Pacific ocean (Salo 1991). In North America, they are found in the coastal streams of northern California, Oregon, Washington, British Columbia (BC), and Alaska (including the Aleutian Islands), as well as the Yukon and Mackenzie rivers in the Arctic. Chums are reported from more than 800 streams in British Columbia, and escapement time series are available for many of these (Slaney et al. 1996). Based on their return run timing, chum are frequently separated into “summer” and “fall” run populations. Despite their importance within the Pacific region, few detailed assessments of the stock status of chum have been undertaken.

The most recent assessment of chum in southern BC was by Ryall et al. (1999) in an area called the “Inner Study Area” (ISA). The ISA includes the east and west coasts of Johnstone (DFO Statistical Areas 12-13) and Georgia (Areas 14-18, 28) straits from the north end of Vancouver Island to Boundary Bay (part of Area 29) and Saanich Inlet to the south (Figure 1). Ryall et al. found that escapements of fall chum returning to upper Vancouver Island, Kingcome, Bond, Toba, and Knight inlets had declined markedly in recent years and concluded that these populations were not responding to reductions in harvest. In contrast, populations returning to Johnstone Strait, Loughbourough and Bute inlets showed moderate growth. More recently, Holtby et al. (2003) stated that chum abundance appeared to be stable or increasing in Areas 7, 8 and 9, but seemed to be severely depressed in Area 10. They also noted that escapements in Areas 7-10 and especially Area 7 continued to be below the nominal CDFO escapement targets but above the estimated S_{MSY} determined for the aggregate in each statistical area.

We describe the status of chum salmon returning to Areas 7-18, Area 28 and part of Area 29, which corresponds to the central coast (Areas 7-13) and the Non-Fraser ISA (Areas 12-18 plus Area 28 and part of Area 29) (Figure 1). Spilsted (2003) describes the status of chum in Canadian waters north of our study area.

There are six main chum stocks[1] in our study area. The first four correspond to the chum returning to Areas 7, 8, 9, and 10 and are referred as the “northern stocks”. Areas 7-10 are remote coastal areas that are primarily accessed by water or by air. Area 7 (Bella Bella) has over 1280 km of coastline within its channels, passes, bays and inlets and is the most convoluted piece of coastline in BC. In contrast, Areas 9 and 10 (Rivers/Smith Inlets) have only 680 km of coastline (Greenlee 1985). In general, chum returning to Areas 7-10 are sufficiently discrete spatially and temporally to enable the fish returning to each area to be managed and assessed separately. The fifth stock consists of those fish returning to Area 11 (Seymour Inlet). The sixth stock comprises fish spawning in the ISA but excludes fish from the Fraser River (Figure 1). We divided this large area into 6 zones: West (WJST, Areas 12 and 13) and East (EJST, Areas 12 and 13) Johnstone Strait, plus Northwest (NWGS, Areas 13 and 14), Northeast (NEGS, Areas 15 and 16), Southwest (SWGS, Areas 17, 18 and 19) and

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[1] We define a stock as a group of salmon spawning in a particular area (s) for which catch can also be estimated (i.e. a manageable group of fish). This definition is similar to Ricker’s 1975 definition of a stock (Ricker 1975). Groupings based on genetics would probably have fewer units since genetic techniques used to date have revealed relatively little stock structure (Park et al. 1993, Taylor et al. 1994, Kondzela et al. 1994, Beacham et al. 1987). A DNA study currently underway should provide improved resolution of stock structure for BC chum salmon (J. Candy, PBS, pers. comm.).

Southeast (SEGS, Areas 28 and 29) Georgia Strait (Figure 1). The fifth and sixth stocks will be referred to as the “southern stock”. This status report focuses on fall run populations, except for chum in Area 8 which is a summer run.

The overall goal of this study is to assess the status of these six stocks of chum salmon and to describe how status varies temporally over the time period 1953-2002. Status assessment is based on escapement estimates and trend analysis of abundance indicators as well as a comparison of escapement to reference points or conservation limits.

We develop reference points to help categorise stock status. Reference points are sometimes measured in terms of fishing mortality units, and sometimes in terms of stock abundance (Mace and Sissenwine 1993; Mace 1994). Myers et al. (1994), and more recently Johnston et al. (2002) emphasize that ultimately it is the spawning stock that must be conserved. We, therefore, base our reference points on spawner abundance. Although, our stock status analysis is based on escapement we performed a similar analysis using total run size to check for consistency in the stock status with that based on escapement. A potential shortcoming of restricting our analysis to large aggregates of stocks is that these often comprise fish returning to many streams and the status of the spawners in each of these streams may be different than that of the overall aggregate. In other words, there may be variability in health within an aggregate. To deal with this, we calculate and compare relative rates of change in escapement per year for individual streams within each aggregate. Finally, we compare our interpretation of stock status based on the complete time series to one based on data from the last three generations only.

2 Methods

2.1 Data requirements and sources

This study requires information on stock identification as well as estimates of enhanced contributions, wild catches and escapements. Estimation methods are described in the following sections.

2.1.1 Stock Identification

In Areas 7-11, fishery managers monitor fish arrival and their migration to various streams within each area. Regional staffs distinguish fish from various areas based on differences in run timing (L. Enderud, DFO Central Coast, pers. comm.). As a result, bias in catch estimates due to fish being misassigned to the wrong area is assumed to be low. For instance, in Area 7, some chum migrate through Milbanke and Finlayson Channel and/or Mathieson Channel in late July or early August to spawn in Kainet Creek and Mussel River. Other chums migrate through Seaforth Channel to Roscoe Creek, Neekas Creek and Kwakusdis River, at the end of August to mid September. Neekas Creek chum, after passing through Seaforth Channel, enter lower Spiller Channel in late August. In Area 8, the summer chum, the only one of importance and actively managed (Greenlee 1985), arrive on average one month earlier than chum in Area 7. This stock comprises three groups referred to as the Bella Coola, Kimsquit and Dean Closed fish whose timing in the Fisher-Fitz Hugh Channel is normally around 15-20 July, 10 August and 20 August, respectively (L. Enderud, DFO Central Coast, pers. comm.). In Areas 9-10, chum arrival ranges from early August to the end of October. In Area 11; all chum have typically entered freshwater by the end of August (L. Hop Wo, DFO South Coast, pers. comm.).

Results from allozyme electrophoretic analysis were used to separate the various components of the ISA stock: Fraser, Non-Fraser ISA and US fish (Hop Wo et al. 1989). Genetic Stock Identification (GSI) samples were collected from 1982-1993, and in 1996 from all major intercepting fisheries. For years without GSI samples, Fraser River/Canadian non-Fraser River contributions were estimated by weekly average historic GSI data for each intercepting fishery.

2.1.2 Enhancement

In order to assess wild populations, we needed to estimate the proportion of fish caught and escaping that were of enhanced origin. Chum salmon have been enhanced in the study area since the late 1970's. Hatcheries are in locations where terminal fisheries can concentrate on enhanced chum stocks while minimizing impacts to non-enhanced stocks. In Areas 7 and 8, there are three enhancement facilities: Kitasoo Creek and Snootli from which are released fresh water-reared fed fry, and McLaughlin Creek from which are released seapen-reared fed fry. However, Snootli Hatchery on the Bella Coola River is the only major facility in the area, utilizing Japanese-style keeper channels and raceways to produce fed fry. Its original purpose was to produce sufficient numbers of summer chum to allow the pink salmon fishery to continue. Snootli Hatchery currently enhances the following lower Bella Coola chum stocks: Snootli, Salloomt, Fish/Airport, and Thorsen creeks. Necleetsconnay Creek[2] was previously enhanced but has not been since 1991. Each year since 1978, a portion of the Snootli Creek fed fry have been released in the creek with an adipose-ventral or ventral only fin clip. In addition, at least one of the other three enhanced stocks is cyclically marked every three years with a different fin clip than those from Snootli creek. In Area 14, there are three enhancement facilities: Big Qualicum and Little Qualicum that produce unfed fry and Puntledge River that releases fed fry. Big Qualicum and Little Qualicum use a spawning channel to increase freshwater survival and hence fry production. Big Qualicum also uses flow control to increase natural fry survival. Puntledge Hatchery uses a combination of modified Atkins boxes, deep gravel matrix boxes/keeper channels, and concrete raceways/seapens to produce chum fry.

Assessment of the enhanced contributions is based on returns of fish that were fin clipped as fry. Little Qualicum enhancement is cyclically assessed by marking a portion of the spawning channel fry released with an adipose clip and a different ventral clip than Big Qualicum. Puntledge chum have typically been marked with an adipose clip and coded-wire tag but have also been marked with other clips; however they have not been marked since the 1997 brood. Not all release groups are represented by a mark. Contributions for those groups are estimated by associating them with a marked release group with a similar size and release timing (D. Bailey, unpub. data).

Enhanced catch was estimated from mark data obtained by sampling the commercial net catch during the offload at various processing plants prior to any grading of the fish. Sampling was usually confined to catches from single statistical areas. Sampling from mixed statistical areas was utilized only when other samples were not available.

The enhancement methodology (field and estimation) was similar through time with the exception of reduced chum marking in recent years, particularly in Areas 8 (D. Bailey, unpub. data). As a result, we believe that there was little temporal bias in annual estimates of hatchery

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[2] Necleetsconnay chum enhancement was stopped primarily because the run had been rebuilt to historic levels, and fin-clip recovery data indicated few were caught in the commercial fishery directed on other Bella Coola stocks (Russ Hilland, DFO Snootli hatchery manager , pers. comm.) .

contribution in the Area 8 catch but that the associated error is likely higher in recent years (D. Bailey, unpub. Data).

Enhanced escapements are estimated by hatchery staff using various techniques such as counting fences (Big Qualicum, McLaughlin, and Kitasoo), mark/recapture (Snootli, Salloomt), and stream walks and dead pitches (Puntledge, Little Qualicum, Salloomt, Fish/Air, Thorsen). With regard to enhanced contribution from the Snootli hatchery, the methodology to estimate the proportion of enhanced fish has remained the same throughout the years (Loosmore, pers. comm.). Escapements are sampled by hatchery staff for marks during brood stock collection, during migration into the hatchery, and during dead pitches of the natural escapement. Detailed information on commercial and escapement sampling and how these enhanced contributions are calculated can be found in Bailey et al. (1988, 1989). Estimates of hatchery origin spawners are thought to be quite reliable by enhancement staff (D. Bailey unpub. data). Enhanced fry releases, catch and escapement contribution data were compiled from a MS ACCESS database (Bateman DFO SEP pers. comm.).

2.1.3 Wild Catch

Total catch estimates for Areas 7-10, 11 and 12-29 were assembled from the post season review report (DFO Central Coast 2003), regional database (Davidson, DFO STAD, pers. comm.) and the clockwork database (McConnell, DFO South Coast, pers. Comm.), respectively. We updated the last three years of the clockwork database. This consisted of assembling catch data from the regional catch databases (data up to 2000 are from the Regional Catch Database and 2001 data are from the Fisheries Operation System (FOS)), and GSI data (Hop Wo, unpub. data). We then partitioned the catch into its origin (Fraser, USA, and Non-Fraser Areas 12-29) using GSI methods (Hop Wo et al., 1993). The ISA catch, excluding fish from the Fraser or the US, was partitioned on a yearly basis between the 6 sub-areas proportional to escapement in these sub-areas. Wild catch was estimated by subtracting the enhanced catch from the total catch.

2.1.4 Wild Escapement

Visual estimates of the numbers of chum salmon spawners in an area often are used as an index of total abundance. Although these estimates may not be accurate, they are the most consistently recorded index of abundance available for wild chum salmon. Certain “indicator streams” have been surveyed reasonably thoroughly and consistently throughout the years. In Area 7, there are 11 of these indicator streams: Mussel, Kainet, Nameless, Salmon Bay, Neekis, Kwakusdis, Kunsoot, Roscoe, Quartcha, Clatse and Cooper Inlet. In Area 7, spawners are enumerated primarily by foot and at times by aircraft. Most of these streams are reasonably small and clear and the chum can be easily and accurately counted (Greenlee 1985). In Area 8, because of the glacial headwaters of the Bella Coola and Kimsquit rivers, enumeration in these very turbid waters is more difficult. As a result, spawners are counted in side channels and tributaries that have good visibility (Greenlee 1985) and these counts are expanded to represent the entire area. In Areas 9 and 10, spawners are counted by foot and using a river boat. In Areas 12-29, enumeration is carried out through a combination of aerial and foot surveys. Annual escapement estimates (BC16 annual escapement summaries) were compiled up to 2002, except for Area 11-29, from the regional database (NuSEDS) and local databases (M. Mortimer M. and P. Zetterberg, DFO Central Coast, pers. comm.). Escapement data for 2002 for Areas 11-29 were not available in time to include in this report.

Wild escapements in enhanced systems were estimated by subtracting the enhanced escapement (also called "natural escapement" in the SEP database) from total escapement (BC16 annual escapement estimate).

2.2 Data Issues

The quality and frequency of annual escapement surveys has most likely varied given the large study area and long time series. Changes in field and estimation methodologies combined with incomplete or missing documentation makes time series analyses of abundance difficult. Even areas such as 7 and 8 experienced changes in estimation methodology (Gordon Curry, Lyle Enderud, DFO, pers. comm.).

To minimize temporal and spatial variability in data quality and quantity, we created a "best data set". The "best data set" is composed of data from indicator streams or other streams that had been surveyed with reasonable consistency through time. To create the "best data set", we partitioned the escapement time series of each stream in roughly four equal intervals: (1953-1964, 1965-1976, 1977-1988, and 1989-2002). A stream was selected if it had an escapement record for at least 50% of the years in each of the time intervals. The streams making up the "best data set" remained constant through time.

Finally, we used three approaches to fill in the missing escapement values: 1) Pmax (Holtby 2000), 2) modified Pmax, and 3) a statistical approach based on regression analysis.

Because we also performed a trend analysis on the total run size, we needed to estimate total escapement from all the streams within each area, not only the streams included in the "best data set".

2.2.1 Imputation technique to treat the missing escapement values in the best data set

2.2.1.1 Pmax and modified Pmax technique

The Pmax technique is an averaging scale technique (Holtby, 2000). First, observed escapement (E) in each stream "i" was scaled to the maximum escapement recorded in that stream across all years t:

$$P_{it} = E_{it} \Big/ \max(E_i)$$

Then the $P_{i,t}$ are averaged across streams "i" within each year "t" and each area to give a time series $P_{\bar{i},t}$ or Pmax. The average stream escapement was then constructed by multiplying Pmax by the average of max (E_i) made across the "i" streams. The modified Pmax technique differs from the original Pmax technique (Holtby 2000), in that stream time series of escapement were standardized to a mean of 0 and standard deviation of 1.

First, we estimated escapement for years with an escapement value. We then assessed the performance of the Pmax and modified Pmax by testing the goodness of fit of the relationship between observed versus estimated escapements. If the method was unbiased one would expect an intercept of 0 and a slope of 1. This is not a "true" validation per se, since the same observations are used to estimate and test the approach, but is rather a measure of goodness of fit.

2.2.1.2 Statistical approach

Construction of the empirical model

We developed an empirical model to predict escapement at time t. The hypothesis being tested was that escapement at time t was a function of escapement from previous year(s) and geographical location. We defined two locations: North and South, which comprised Areas 7-11 and the Non-Fraser ISA, respectively. A developmental data set composed of 75% of the observations from the “best data set” was randomly selected from each location and time period. Escapement data were lagged from 1-5 years. Escapement data were logarithmically transformed (base 10) to stabilize variances and regressed against various combinations of timed lagged escapements along with the categorical variable, location. Variables were selected using stepwise regression (0.2 and 0.05 were the significance levels for a variable to enter and remain in the model, respectively). The best models were identified by high adjusted R^2 values and small mean square errors (MSE).

Model validation

The best models were validated using an independent data set, which was the remaining 25% of the observations from the “best data set”. Validation consisted of regressing observed escapements from the independent data set against predicted escapements with the empirical model based on the developmental cases. An intercept of 0 and a slope 1 would be expected if the empirical model was unbiased. High adjusted R^2 and small mean square error (MSE) values provided an indication of the predictive power and error prediction of the model.

2.3 Filling the missing escapement and scaling

The best imputation technique was used to fill the missing escapement values for the streams from the best data set and from the remaining streams, whenever possible (if the empirical model is the best approach it will depend on the model predictors and the pattern of the missing values). Total escapements for the complete data sets (all streams) were estimated by summing escapements from each of the streams within each area.

2.4 Trend Analysis

Trends in escapement were analysed using the “best data set” both at the area (stock level), and within each area (stream level). We also analysed trends in total run size[3] and compared these with escapement trends. Trend analysis in escapement and total run size were performed on the complete time series and on the last 12 years (3 generations), by fitting an ordinary least squares regression. Note that our goal was not to explain yearly variations in escapement but rather to describe the overall trend by minimizing the impact of extreme values. To minimize the impacts from outliers, we smoothed the escapement time series by calculating running averages over 4-year periods, the dominant age class for chum salmon throughout B.C.

[3] Trend analysis on total run size was done on the complete data set (all streams in each area) as it required an escapement estimate from all streams.

Variability in status within stock groupings was quantified by summing the number of streams in each of the three classes of relative rate of change in escapement per year: ≤ -5%,> -5% and < 0%, and ≥ 0%. The first two classes correspond to a reduction in the number of spawners to one-half or less, and between 20% and 49% of the original number in three generations, respectively. We used the slope of the relationship between the natural logarithm of the 4-year moving escapement average against year as an estimate of the relative change in escapement per year (Gujarati 1998).

2.5 Reference points

Escapement basis:

We calculated two reference points based on the long term median escapement (LTME), which defined three zones or states (red, amber, and green). When 60% LTME < escapement < 80%LTME, stocks are in the amber zone; when escapement ≤ 60% LTME, stocks are in the red zone, and when escapement ≥ 80% LMTE, stocks are in the green zone. We acknowledge that these boundaries are arbitrary and their usefulness in assessing stock status will require cross-validation work, perhaps involving other reference points such as the number of spawners at MSY.

To describe the state of the stocks over time (full time series), we summed the numbers of years that a stock was in each of these zones. We further summarized this information by focusing on the number of years for which yearly escapement were in the red zone using broad quantifiers such as below average (<10 yrs), average (10-13 yrs), and above average (≥14 yrs).

To describe the state of the stocks during the last three generations, we used the same approach as for the full time series but with the following quantifiers: below average (<3yrs), average (4-6 yrs), and above average (>6 yrs) as the number of years for which yearly escapements were in the red zone. In addition, we qualified the escapement of the last 3 generations being in the "red", "amber", or "green" depending on which category the median escapement of the last three generations fell within: ≤ 60% LTME, >60% LTME - < 80%LTME, or ≥ 80% LMTE.

Total Run size:

The same boundaries (≤ 60%, 60%-80%, ≥ 80%) for escapement reference points were used to calculate reference points based on the long term median total run size (LTMRS), and to define three zones or states (red, amber, and green). The status of the stocks based on total run size was described in the same way as that based on escapement.

3 Results

3.1 Data description

Escapements to Big Qualicum, Little Qualicum and Puntledge rivers were removed from our data set because wild escapements were estimated or recorded inconsistently through time. Big Qualicum stock is considered to be totally enhanced. We reviewed hardcopies of the relevant BC16's for these rivers but the information necessary to estimate wild escapements was not available. For instance, in some years hatchery fish were included in the annual escapement estimate, in other years they were not, in some years brood stock were included, in other years, they were not.

Streams with at least one escapement record in each of four time periods (N=419 streams) ranged from 4 in Area 10 to 76 in East Johnstone Strait (Table 1). Plots of the cumulative number of streams against the cumulative median escapement of the complete set of streams and streams from the "best data set" (both with missing values – before filling the blank) for each area are in Figure 2. Based on the complete set of streams, except for Areas 11 and 10, between approximately 15% and 25% of the streams had at least 80% of the total escapement (Figure 2). In Areas 11 and 10 , roughly 35% and 60% of the streams had 80% of the escapement.

For all areas combined, the number of streams surveyed at least 50% of the time drops roughly by 20-30 streams per time period. This is particularly true for the southern streams (Table 2). As a result, our "best data set" comprises only 166 streams (69 northern streams, 97 southern streams), i.e. 166 streams were surveyed at least 50% of the years in each of the four time periods from 1953 to 2002 (Appendix 1). The number of streams per area is in Table 1. It is worth noting that less than 10% of the observations were missing in the "best data set".

3.2 Treatment of missing escapement values

3.2.1 Pmax and modified Pmax Techniques

Figure 3 show a regression of observed against "predicted" escapement using the Pmax and modified Pmax for the complete and "best data" sets. These plots showed that the relation accounts between 60% and 65% of the variation in escapement. However, as illustrated by the many observations below the 1:1 line, both methods tended to underestimate escapements Goodness of fit tests showed that both techniques tended to be biased as shown by an intercept and a slope significantly different from 0 and 1 ($p>F <0.0001$), respectively (Table 3). The modified Pmax technique was less biased than the Pmax as indicated by a greater Adj-R^2 and a lower MSE for both data sets.

3.2.2 Empirical model predicting escapement at time t

When using the full model as described below

$$LogE = \alpha + \beta_1 LogE_{t-1} + \beta_2 LogE_{t-2} + \beta_3 LogE_{t-3} + \beta_4 LogE_{t-4} + \beta_5 LogE_{t-5} + INTER + B_6 LOC$$

where E_{t-1} to E_{t-5} refers to escapement at time t-1 and t-5, respectively, INTER refers to all interactions between $E_{t's}$ and LOC, and LOC refers to location (=1 if North and =0 if South).

The only variables that remained ($P \leq .05$) in the stepwise regression model were E_{t-1}, E_{t-4} and the interaction term $E_{t-1} \times E_{t-4}$.This model explained 62.6% of the variation in escapement at t and had a MSE of 0.5346 (Model A, Table 4). Plot of observed escapement versus predicted escapement showed that the fit is fairly good in that most observations are distributed around the 1:1 line with the presence of some outliers (mostly observed escapement lower than predicted). The final model (Model B, Table 4) was obtained after removing outliers (residuals exceeding 1.5), which represented less than 1.4% of the observations. This model explained 66.6% of the variation in escapement and had a MSE of 0.491 (Figure 4).

Model validation was performed on an independent data set comprising 1522 observations. The relationship between observed and predicted counts of the independent data set had an intercept not significantly different from zero (p=0.35, t-test), a slope significantly different from 0 ($p < .0001$) and an R^2 of 62.7% (Model C, Table 4). The refitted model without an intercept (Model D, Table 4), had a slope not significantly different from 1 ($p<0.0001$) explained 97.4% of the variance (Figure 5). This implies that model B was unbiased and had good predictive power. Figure 6 showed that model fit fairly well regardless of the area while Figure 7 showed that the residuals generally were distributed equally above and below the 0 line.

3.3 Filling in missing values and scaling

Of the three imputation techniques used, we selected Model B to fill the missing escapement values as it was unbiased and explained a high percentage of the variation in escapement of an independent data set (97%). Model B was then used to generate escapements for each of the missing value as well as for the outliers. This was possible for all missing values, except for 39 observations, for which escapements at t-1 and t-4 were not available. These were filled using the modified Pmax technique.

The applicability of model B to the remaining streams was, however, limited by the number of missing values and the pattern of the missing values (too many missing escapements at t-1 and t-4). To overcome this we used the modified Pmax technique to estimate a scaling factor. The scaling factors are simply the ratios of the total number of spawners in the complete data set over the total number of spawners in the best data set per area and year (both based on the modified Pmax technique). We chose the modified Pmax to estimate the scaling factors, because, contrary to the usual Pmax technique, the direction of the bias of the modified Pmax technique tended to be consistent in both the “best data set” and the “complete data set” (Figure 3). As a result, we expected that the scaling factor ratios would be unbiased.

The medians of these ratios in each area were used to scale the “best data set” (in which missing values were filled as described above) and hence created an estimate of total escapement in the “complete data set”. The median and coefficient of variation of the scaling factors for each area are in Table 5.

3.4 Stock status

The reader is referred to Figures 8-11 and Tables 6a and 6b. Figures 8 and 9 illustrate trends in escapement and total run size, respectively. Figure 10 shows the numbers of streams according to their annual rate of change in escapement. List of streams with their relative rate of change in escapement are in Appendix 1. Figure 11 show patterns in exploitation rates. Note that Figure 8 and 10 are based on our best data set, while Figure 9 and 11 are based on the complete data set (all streams from each Area). Tables 6a and 6b summarize information from Figure 8-10. We group results for stocks (areas) when they are similar. For each stock (or group of stocks) we present results first from the complete time series (1953-2001 or 2002), and second from the most recent three generations (1990-2002 for Northern Stocks and 1989-2001 for Southern Stocks).

Areas 7 and 8

Complete time series (1953-2002)

Areas 7 and 8 were grouped because they had relatively high long-term median spawners (~183,200 and ~141,400) and other similar characteristics. Both areas had highly variable temporal patterns in escapement without an overall trend (Fig. 8) as well as the lowest and below average number of years with escapement in the red zone. For Areas 7 and 8 respectively, 21 (3 + 18) out of the 28 (3 + 19 + 6), and 14 (6+8) out of the 18 (6+8+4) streams with significant trends in escapement had a negative rate of change (Table 6a). Of the 21 streams of Area 7, 3 and 18 streams had a negative rate of change of at least 5% and less than 5% per year, respectively. Figure 10 reveals that the median escapements to streams that increased were greater than for streams that declined. No overall trends in escapement at the stock level were due, in part, to the tendency for streams with low spawner abundance to decline through time, while streams with more spawners increased (Fig. 8). Both areas also had the highest exploitation rates (54%, 60%) (Fig.11, Table 6a).

Total run size showed a negative trend in Area 7 and a positive trend in Area 8 (Fig. 9). Total run sizes had average and above average numbers of years in the red zone, for Area 7 and 8 respectively.

Last three generations (1990-2002)

Areas 7 and 8 escapements tended to increase during the last three generations and the median escapements were above the long-term median escapement (202,300 and 172,700) (Table 6a b). Increased escapements were due to the large proportion of streams (15 out of 20 and 10 out of 11) that had positive trends in escapement (Table 6b) and the fact that many of the increasing streams had large numbers of spawners (Fig. 10). During the last 12 yrs, in Areas 7 and 8, the number of years with escapement in the red zone were below average (≤3 out of 13 years) (Table 6b) while escapements were in the green zone. In addition, exploitation, at least for Area 7, declined (from 54% to 37%) (Fig.11). Contrary to escapement trends, median total run sizes during the last 3 generations were lower and similar to the long term median in Areas 7 and 8, respectively. Both Areas had a below average number of years (≤3 yrs out of 13 years) with total run size in the red zone (Table 6b). Median total run size was in the amber and green zone in Areas 7 and 8, respectively.

Areas 9 and 10

Complete time series

Areas 9 and 10 had fairly low long-term median numbers of spawners (24,400, 17,200). Escapements varied temporally with no overall trend. The northern stocks had the greatest numbers of years with escapements in the red zone (14/50, 11/50) (Table 6a). In Area 9, all 5 streams with significant trends in the escapement had negative rate of change over time (Fig. 10). Exploitation rates declined from peaks of 70%-80% in the late 1960's and early 1970 to zero in recent years (Fig. 11).

In both Areas, contrary to escapement trends, total runs declined (Fig. 9) and there was an above average number of years with total run sizes in the red zone (16/50, 19/50) (Table 6a).

Last three generations

Recent escapements to Area 9 tended to increase while in Area 10 escapements tended to decline (Fig. 8). This is due to the fact that escapements to all the streams (3) in Area 10 declined at a rate of at least 5% per year, while 5 of the 6 streams in Area 9 had a significant increase in escapement which counterbalanced the decline in the remaining stream (Fig. 10b). Nonetheless, recent escapements to Area 9 (15,400) were in the amber zone and lower than the long term median by 35%, while those to Area 10 were similar to the long term median and in the green zone (Table 6b). During the last three generations, exploitation rates declined sharply, particularly in Area 10 (Fig. 11).

Total run sizes during the last three generations declined in Area 9. Both Areas had an average number of years with runs in the red zone and total run sizes in the amber zone.

Area 11

Complete time series

Area 11 had a long-term median escapement of 25,300 (Table 6a) and while temporal patterns varied, there was a tendency for an overall decline (Fig. 8). This was due in part to the fact that 4 out of 6 streams that had significant negative changes in escapement also had high spawner abundances (Table 6a). Exploitation rates declined from ~60% in the mid 1980's to 0 in the last 6 years. This stock had an average number of years with escapement in the red zone.

Total run size showed no trend and had a below average number of years in the red zone.

Last three generations:

There is no trend in recent escapements. However, the median escapement (20,000) of the last 3 generations was in the amber zone. Two out of the three streams that had significant changes in spawners/yr declined by at least 5% per year in the last three generations.

Total run size tended to decrease during the last three generations. Nonetheless, the number of years with total run size in the red zone was below average and the median total run size was in the green zone.

WJST

Complete time series

WJST has a long-term median spawner abundance of 36,500. Escapements were highly variable with no overall trend. WJST's escapements had an above average number of years in the red zone. Two out of 5 WJST streams that demonstrated a significant trend had a declining rate in escapement of at least 5% per year. These particular streams had historic record low spawner abundances (Fig. 10a, Table 6a).

Conversely, long-term median total run size was 68,500. Total run sizes showed no trend but were found in the red zone more often than average.

Last three generations

A negative trend was detected for recent escapements (Fig. 8), though the number of years in the red zone was below average (Table 6b). WJST's escapement is well in the green zone, and recent medians were above the long term median of escapement (Fig. 8).

Total run sizes tended to have a pattern similar to escapement: negative trend, an above number of years with run size in the red, with runs well in the green zone.

NWGS

Complete time series

NWGS had 20,300 spawners with highly variable escapements but no overall trend, and an average number of years in the red zone. Nine out of the 10 streams that had significant changes in spawners/yr had a negative rate (Fig. 10).

Total run size was 31,900 with a negative trend, although the number of years (8) in the red zone was below average (< 3 yrs).

Last three generations

NWGS shows a positive trend in escapement, with a number of years less than average in the red zone (< 3 yrs). Twelve out of the 13 streams that had a significant rate of change in escapement had a positive rate of increase (Table 6b, Fig. 10b). Median escapement for the last three generations was in the green zone.

Trends in total run sizes were similar to escapements; both were positive, had average numbers of years in the red zone, and median run sizes and escapements were in the green zone.

SWGS, NEGS, SEGS

Complete time series

SWGS, NEGS, and SEGS stocks have fairly high numbers of spawners (157,800, 93,500, and 52,100) that show variable but increasing trends in escapement (Table 6a, Fig. 8). For each stock, the streams with declining escapements tended to be streams with low spawner numbers (Fig. 10a). The occurrence of escapement in the red zone was average.

Total run sizes were substantial (155,000, 222,000, 205,000), and like escapement data, were increasing with an average or below average (SWGS) frequency of total run sizes in the red zone.

Last three generations

Recent escapements in SEGS and NEGS showed no trend but they declined in SWGS. SWGS had a preponderance of streams (7 out 10 with significant trend) in the most significant decline category (≤ 5%). There was no decline in exploitation rates (0.28), which were similar to the long time series (0.31). Overall, escapements of all three stocks were in the green zone. Recent median escapements were greater than their long term medians (93,500 vs. 120,100, 157,800 vs. 202,200, 52,100 vs. 78,300) for SWGS, NEGS, SEGS, respectively.

Total run size had similar characteristics. Escapement showed no trend except in SWGS which declined. All three stocks had run sizes in the green zone, with the median for the last three generations (222,400 vs. 308,400, 204,900 vs. 296,300, 155,600 vs. 133,700) greater than the long term median for all three area, except for NEGS which was slightly below.

EJST

Complete time series

Long-term median escapement was 132,400. This stock is unique in that escapement showed a negative trend, and tended to have an above number of years in the red zone (Table 6a). This is in part due to the fact that of the 17 streams that had a significant trend in escapement, only one increased.

Total run size exhibited a similar pattern to escapement including a negative trend, and tended to have an above average number of years in the red zone.

Last three generations

Escapement declined during the last three generations (Fig. 8b). Median escapement was in the red zone and less than 50% of its long-term median (132,400 vs. 50,700) (Table 6b). Of the 16 streams that had a significant change in escapement, 14 declined and for 13 of these, the rate of decline exceeded 5% per year (Fig. 10b). Above average numbers of years had escapements in the red zone.

Total run size exhibited a similar pattern to escapement which included a negative trend, a median run size in the red zone of roughly 50% of the long-term median (210,800 vs. 103,500), and an above average number of years in the red zone.

4 Brief Discussion

4.1 Imputation technique to treat the missing escapement values

When dealing with escapement datasets, data gaps (i.e. missing data) are common and make trend analyses difficult to undertake. The predictive model of escapement developed in this study was unbiased and had predictive power. Nonetheless, the applicability of this approach is limited by the pattern of missing values in relation to the predictors necessary to make the predictions. Fortunately, in our best data set we were unable to fill the missing values for only 39 observations.

The Pmax and modified Pmax technique are based on the concept of "averaging over" and are less restrictive than the regression approach. These techniques require a minimum of one escapement value for at least one stream from each area in any given year only. However, the technique might be biased. Both the regression approach and Pmax technique are single imputation techniques, i.e., only one value is considered for each missing value. The fundamental issue when missing data are replaced by only one set of imputed values is that later analyses will not reflect missing-data uncertainty. Furthermore, the problem becomes worse as the rates of missing information and the number of parameters increases (Schafer

1997). In the future, multiple imputation (MI) techniques should be considered to deal with missing-data uncertainty, i.e., more than one value would be considered for each missing value.

4.2 Possible bias in escapement for Area 10

Surveys and methodologies have changed through time. This is particularly the case for Area 10. Previous to 1997 there was one Charter Patrol staff dedicated to enumerating fish in Area 10 streams. In 1997, with budgets decreasing and an absence of targeted net fisheries in Areas 9 and 10, there was a shift in focus and effort was reduced to one Charter Patrol staff to inspect streams in both Areas 9 and 10. The reduction in effort was reflected by decreased numbers of stream inspections and a shift in the timing of the inspections (earlier and not as effective for chum). Also, there was a change in the Charter Patrol staff member enumerating the streams in Area 10. The Gwa'Sala Nakwaxda'xw fisheries program started counting fish in the Nekite Spawning Channel and River in 1995. In 1996 and 1997 they did not work in the area but have worked there from 1998 to the present. Unfortunately estimates for the river are not available for many years (L. Enderud, pers. comm). Consequently, the negative trend in escapement during the last generation in Area 10 is likely an artefact due to less efficient surveys.

4.3 Limitations of stock status assessment based on escapement data

Since our assessment of stock status was based primarily on escapement data with potentially considerable uncertainty around the estimates, results should be interpreted with caution.

We used both trend and reference points, because trend analysis in escapement alone may not reflect the status. For instance, a negative trend in escapement might be observed even though the escapement is in the amber and green zone. In addition, trends in escapement can be influenced by management practices. Caution is also needed because we used arbitrary reference points to define various status zones (red, amber, green). These reference points need to be put in a biological context, such as the number of spawners at MSY. We do not present results of R/S analysis and Smsy because of the unknown errors in wild catch and age composition data. A R/S analysis in conjunction with a decision analysis would be useful to better describe the state and the likely state under various management scenarios.

5 Summary of stock status and recommendations

Chum salmon in Areas 7 and 8 were generally in the green zone. There appears to be no major management concerns with these stocks. Nonetheless, we recommend that Area 7 chum should be monitored closely as total run sizes appear to have declined ~22% in the last three generations.

Although escapements to Area 9 increased during in the last three generations, trends in total runs were not apparent, and recent median escapements and total run sizes were in the amber zone. Furthermore, the numbers of years with escapements and total run sizes in the red zone for both the long term and the last 3 generations tended to be generally above average, raising the possibility of over-exploitation early in the time series (Fig. 8 and 9). However, exploitation rates are currently low.

Area 10 is in the green zone for escapement and the amber zone for total run size.

Current exploitation of this stock is extremely limited. Our ability to assess Area 10 is hampered by a lack of good quality data. Escapement data are currently gathered from four streams and only three of these have a good time series. It may be worthwhile combining Areas 9 and 10 in future stock assessments or attempting to reconstruct or verify some of the time series.

In Area 11, recent escapements were in the amber zone while total run sizes were in the green zone, albeit declining. Exploitation rates were generally low, except for a period in the 1980's, when this stock was in the amber zone (Fig. 8).

There was significant variability in status among the southern stocks. Stocks on both sides of Johnstone Strait declined recently. However, recent escapements and total run sizes are in the green zone and above the long term median in WJST while both are in the red zone in the EJST.

Interestingly, recent chum escapements and total run sizes in NWGS were in the green zone and showed evidence of a significant increase during the last three generations. This increase may be related to changing fishery practices on enhanced chum returning to this area. Chum returning to NEGS, SWGS, and SEGS have similar patterns. For all three of these stocks, recent escapements and total run sizes are in the green zone. We are concerned with the paucity of streams enumerated in SEGS.

We note some apparent longitudinal patterns: Northern stocks Area 7 and 8 tended to sustain higher exploitation rates than the Southern stock complex.

Studies to calibrate escapement indices to catch and abundance would be useful in the future.

In summary, no stocks appear threatened by extinction. We draw attention to the declining populations in EJST. Additional work is needed to understand the mechanisms responsible.

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Table 1. Numbers of streams surveyed at least once in the complete time series (complete series) and at least 50% of the years (50%) in each of the four time periods (1:1953-1964, 2:1965-1976, 3:1977-1988, and 4:1989-2002).

Stock (Area)	Complete series	50%
7	60	37
8	34	21
9	19	8
10	4	3
11	21	9
WJST	23	6
NWGS	33	14
SWGS	24	11
EJST	76	26
SEGS	73	6
NEGS	52	25

Table 2. Numbers of northern (Areas 7-10) and southern (Areas 11-19, 28-29) streams surveyed within various time intervals and at least 50% of the years in each of the four time periods (1:1953-1964, 2:1965-1976, 3:1977-1988, and 4:1989-2002). For example, of the 85 northern streams surveyed 50% of the years during 1953-1964, 81 of these streams were also surveyed 50% of the years during 1965-1971. In addition, the number of streams with at least one record of chum over the complete time series (NChum) is provided.

Time intervals	North	South
1953-1964	85	175
1965-1976	81	142
1977-1988	78	119
1989-2002	69	97
NChum	117	302

Table 3. Goodness of fit of the log-log base 10 relationship between observed escapement ($OEsc_t$) and predicted escapement ($PEsc_t$) using the Pmax (A) and the modified Pmax technique (B), using the complete data set and the best data set. The probability of a greater F (P), the standard error of the coefficients (SE), the mean square error (MSE) and the Adjusted R^2 (Adj-R^2).

Model	P>|t|	SE	MSE	Adj-R^2 (%)	N
Complete data set					
	<0.0001	0.0235	0.5561	60.3	10901
A) Log $OEsc_t$ = - 0.1035	<0.0001	0.0074			
+ 0.9470 Log $PEsc_t$					
B) Log $OEsc_t$ = - 0.3789	<0.0001	0.0233	0.5235	64.8	10901
+ 1.0331Log $PEsc_t$	<0.0001	0.0073			
“Best data set”					
A) Log $OEsc_t$= - 0.4411	<0.0001	0.0342	0.5437	59.9	7306
+1.05795 Log $PEsc_t$	<0.0001	0.0101			
B) Log $OEsc_t$ = - 0.5526	<0.0001	0.0332	0.5243	62.7	7306
+ 1.0822 Log $PEsc_t$	<0.0001	0.0097			

Table 4. Regression models predicting escapement at time t (Esc_t) as a function of escapement at time t-1 (Esc_{t-1}), t-4 (Esc_{t-4}), and the interaction term ($E_{t-1} * E_{t-4}$). The probability of a greater F (P), the standard error of the coefficients (SE), the mean square error (MSE) and the Adjusted R^2 (Adj-R^2), and the number of observations (N). All variables were log10 transformed. Model development based on A) 75% of the "best data set", B) as A without the outliers. Model validation using an independent data C) fit between observed and predicted with an intercept, and D) without an intercept.

Model	P>|t|	SE	MSE	Adj-R^2 (%)	N
A) Log Esc_t = + 0.6679	<0.0001	0.0986	0.5346	62.6	4515
+ 0.3922 Log E_{t-1}	<0.0001	0.0340			
+ 0.2878 Log E_{t-4}	<0.0001	0.0335			
+ 0.0311 Log E_{t-1} x Log E_{t-4}	<0.0018	0.0099			
B) Log Esc_t = + 0.59246	<0.0001	0.0912	0.4911	66.8	4454
+ 0.4249 Log E_{t-1}	<0.0001	0.0315			
+ 0.3114 Log E_{t-4}	<0.0001	0.0309			
+ 0.0233 Log E_{t-1} x Log E_{t-4}	<0.0015	0.0092			
C) Log Obs= + 0.0586	<0.3468	0.0622	0.5285	62.7	1521
+ 0.9799 Log Pred	<0.0001	0.0194			
D) Log Obs= + 0.9977 Log Pred	<0.0001	0.0042	0.5285	97.4	1522

Table 5. Median scaling factors (SF) are the ratios of the total number of spawners in the complete data set over the total number of spawners in the “best data set” per area and year (both based on the modified Pmax technique). Coefficients of variation (CV) are also provided.

Stock	SF	CV
7	1.066	2.3
8	1.037	2.8
9	1.189	12.1
10	1.177	19.1
11	1.256	9.5
WJST	1.346	20.7
EJST	1.212	13.3
NWGS	1.222	9.6
NEGS	1.229	12.5
SWGS	1.062	3.4
SEGS	2.645	36.2

Table 6a. Summary of statistics based on the entire time series that were used to categorise stock status based on escapement and total run size. Except for the median (LMTE, LMRS), the number in the cell refers to the number of years in each status zone (red, amber, green) or in each class of relative rate of change of escapement per year (%/yr, ≤ -5%,> -5% and < 0%, ≥ 0%, unclassified). Arrows indicate direction of trends (i.e. up or down), when they exist. Note that the statistics on escapement are based on the “best data set” while those for the total run size are based on the “complete data set”.

	ESCAPEMENT									TOTAL RUN SIZE				
	AGGREGATE (Area)					Within Area (stream)				AGGREGATE (Area)				
						% change/yr.								
(Area)	LTME	Green	Amber	Red	Trend	≤ -5	-5 - 0	≥0	Unclas-sified	LMRS	Red	Amber	Red	Trend
7	183,200	34	10	6		3	18	6	10	383,700	27	10	13	↓
8	141,400	33	10	7		6	8	4	3	374,900	28	4	18	↑
9	24,400	29	7	14			5		3	46,400	27	7	16	↓
10	17,200	33	6	11			1	1	1	40,800	27	4	19	↓
11	25,300	31	7	12	↓		4	2	3	34,600	34	8	9	
WJST	36,500	27	4	18		2	1	2	1	68,500	29	1	19	
EJST	132,400	30	4	15	↓	4	12	1	9	210,800	34	1	14	↓
NWGS	20,300	31	8	10		3	6	1	4	31,900	33	9	8	↓
NEGS	93,500	29	7	13	↑	5	6	10	4	155,600	31	7	11	↑
SWGS	157,800	28	10	11	↑	5	2	3	1	222,400	31	10	8	↑
SEGS	52,100	35	2	12	↑		1	3	2	204,900	31	8	11	↑

Table 6b. Summary of statistics based on the last 3 generations series that were used to categorize stock status at the aggregate level (based on escapement and total run size) and within the aggregate level (based on escapement at the stream level) for each area. Except for the median (LMTRE, LMTRS), the number in the cell refers to the number of streams in each status zone (red, amber, green) or in each class of relative rate of change of escapement per year (%/yr, ≤ -5%,> -5% and < 0%, ≥ 0%, unclassified). Arrows indicate direction of trends (i.e. up or down), when they exist. The letters (R,A,G) to the right of LTME and LMRS refers to stock status zones (red, amber, green).

	ESCAPEMENT									TOTAL RUN SIZE				
	AGGREGATE (Area)					Within Area (stream)				AGGREGATE (Area)				
						% change/yr.								
(Area)	LTME	Green	Amber	Red	Trend	≤ -5	-5 - 0	≥0	Unclas-sified	LMRS	Red	Amber	Red	Trend
7	202300/G	9	3	1	↑	3	2	15	17	298,400/A	6	4	3	
8	172700/G	10	1	2	↑	1		11	9	374,900/G	9	2	2	
9	15400/A	5	2	6	↑	1		5	2	33,800/A	4	3	6	
10	16300/G	7	1	5	↓	3				29,600/A	6	2	5	↓
11	17200/A	5	3	4		2		1	6	28,000/G	7	4	2	↓
WJST	62900/G	10	0	3	↓	1		3	2	116,800/G	10	0	3	↓
EJST	50700/R	3	1	9	↓	13	1	2	10	103,500/R	4	0	9	↓
NWGS	14800/G	6	4	3	↑	1		12	1	29,700/G	9	1	4	↑
NEGS	120100/G	8	3	1		7	1	6	11	133,700/G	7	4	2	
SWGS	202200/G	8	4	1	↓	8			3	308,400/G	7	5	1	↓
SEGS	78300/G	12	0	0		2		3	1	296,300/G	11	2	0	

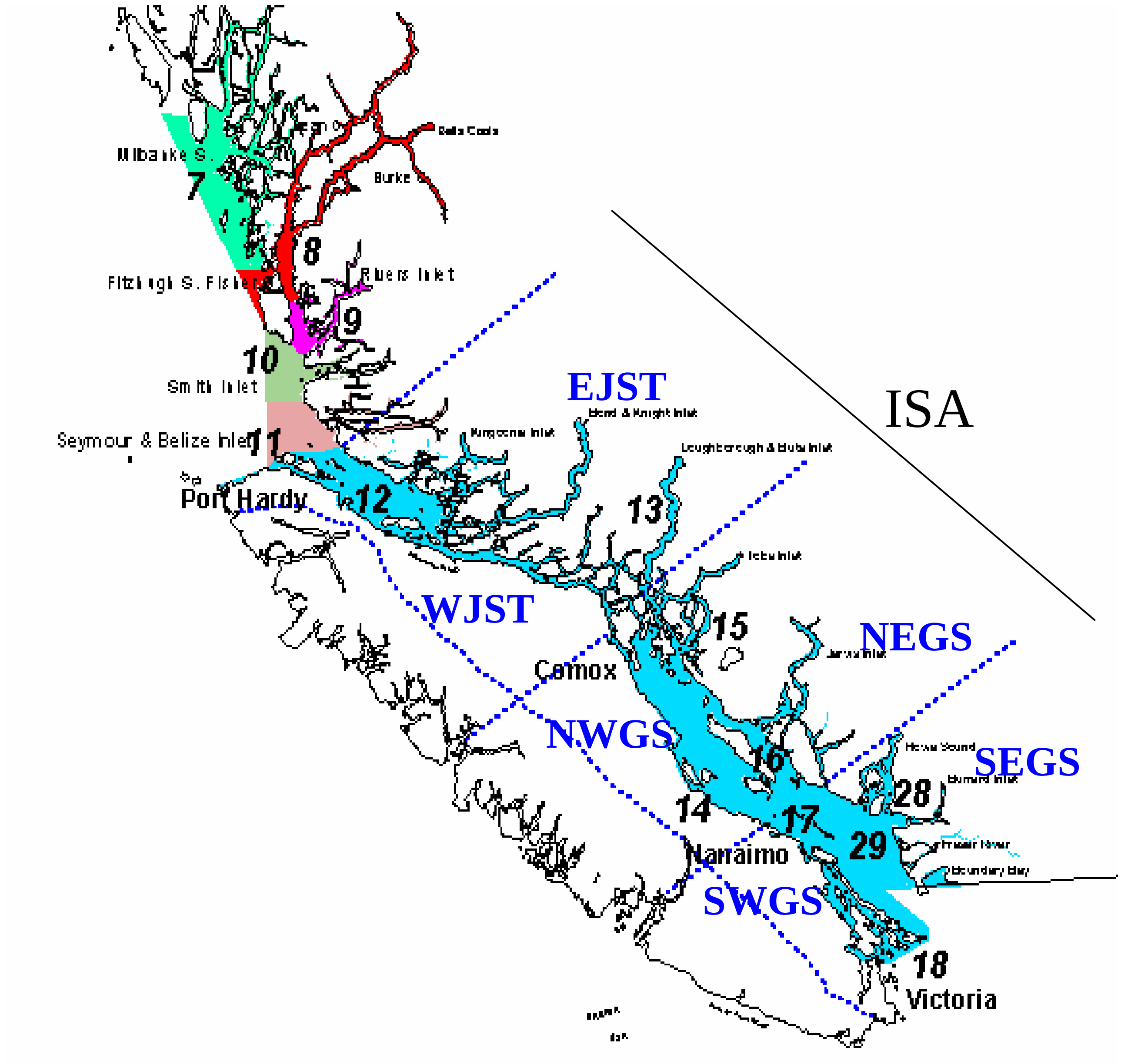

Figure 1. Map showing locations of DFO Statistical Areas 7-18, 28 and 29 in our study. Six components of the Inner Study Area (ISA) contributing to our southern stock aggregate: WJST and EJST indicates West and East sides of Johnstone Strait, NWGS and NEGS indicates North West and North East side of the Strait of Georgia, and SWGS and SEGS indicates South West and South East sides of the Strait of Georgia. Note that ISA exclude chum returning to Seymour and Belize inlets (Area 11), the Fraser River (Area 29) and south of Saanich Inlet (Areas 19 and 20).

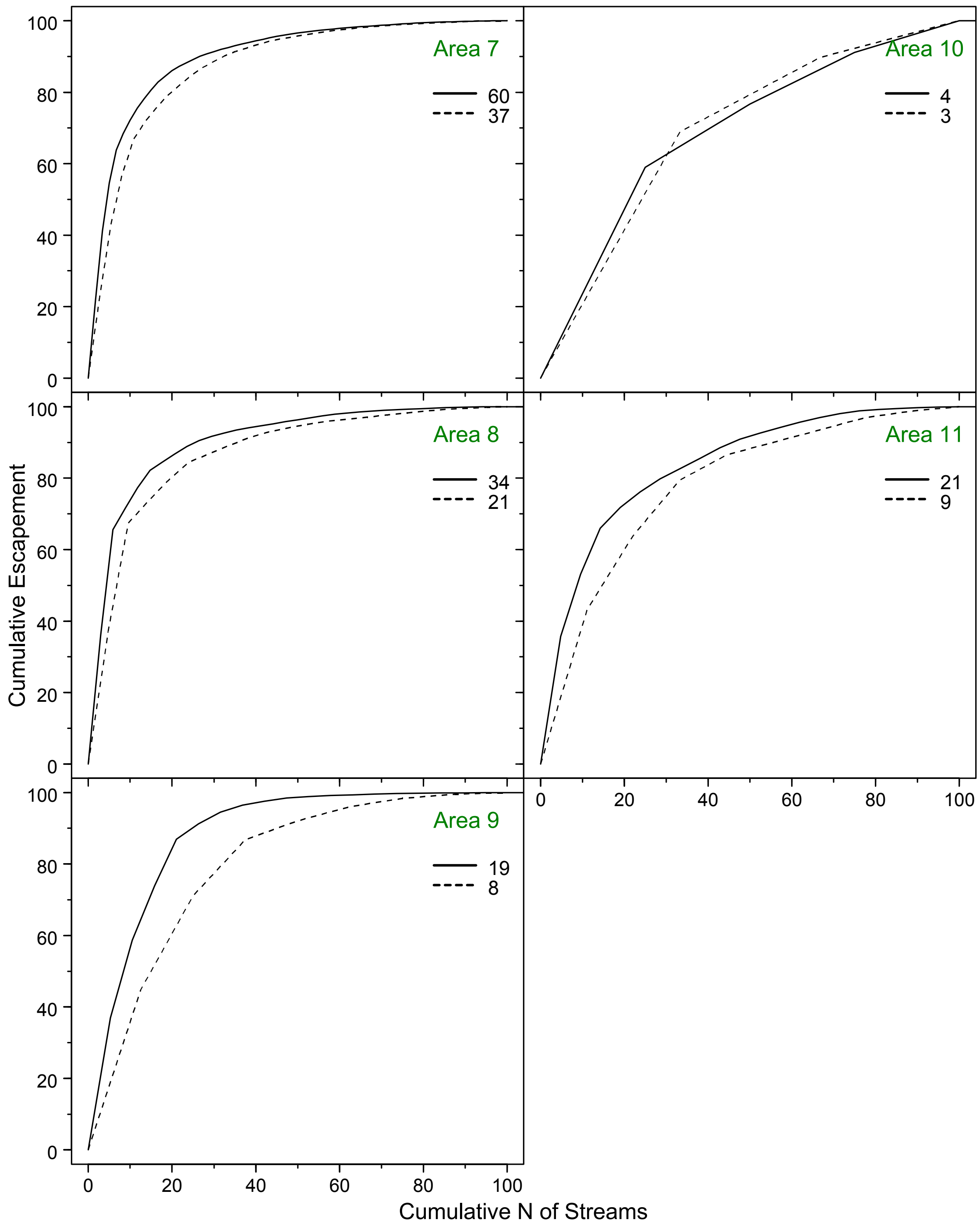

Figure 2. Cumulative median escapement versus cumulative number of streams (percentages) for each stock for the complete data set (solid line) and the “best data set” (broken line) in each area. Numbers in the upper right corner are the numbers of streams in each data set.

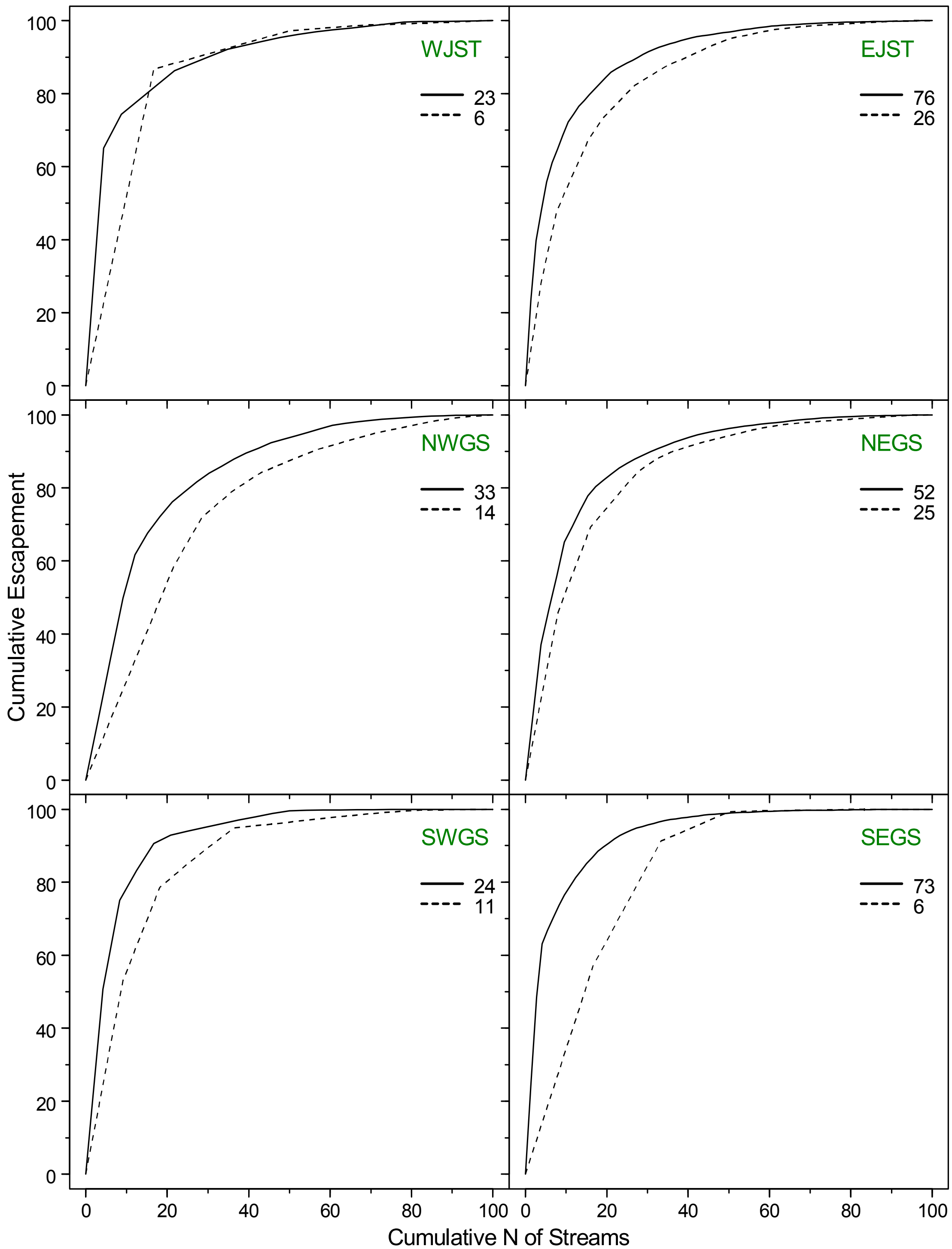

Figure 2. Continued

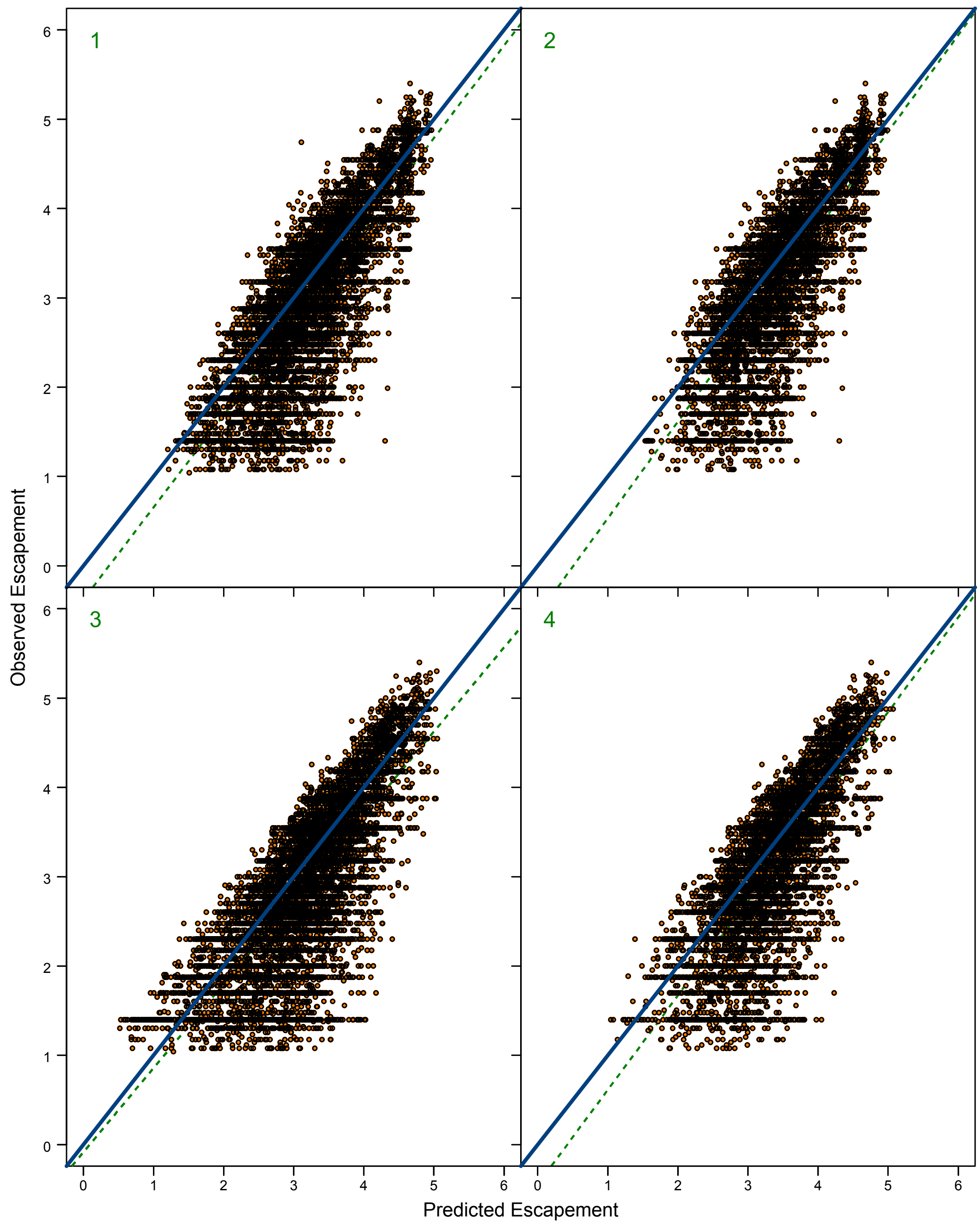

Figure 3. Plot of observed (vertical axis) versus predicted (horizontal axis) escapement in log base 10 using the modified PMAX (1, 2) and the Pmax technique (3, 4), based on the complete dataset (left panel) and the best data set (right panel). The 1:1 line (solid line) and the ordinary least square fitted line (dotted line) are shown.

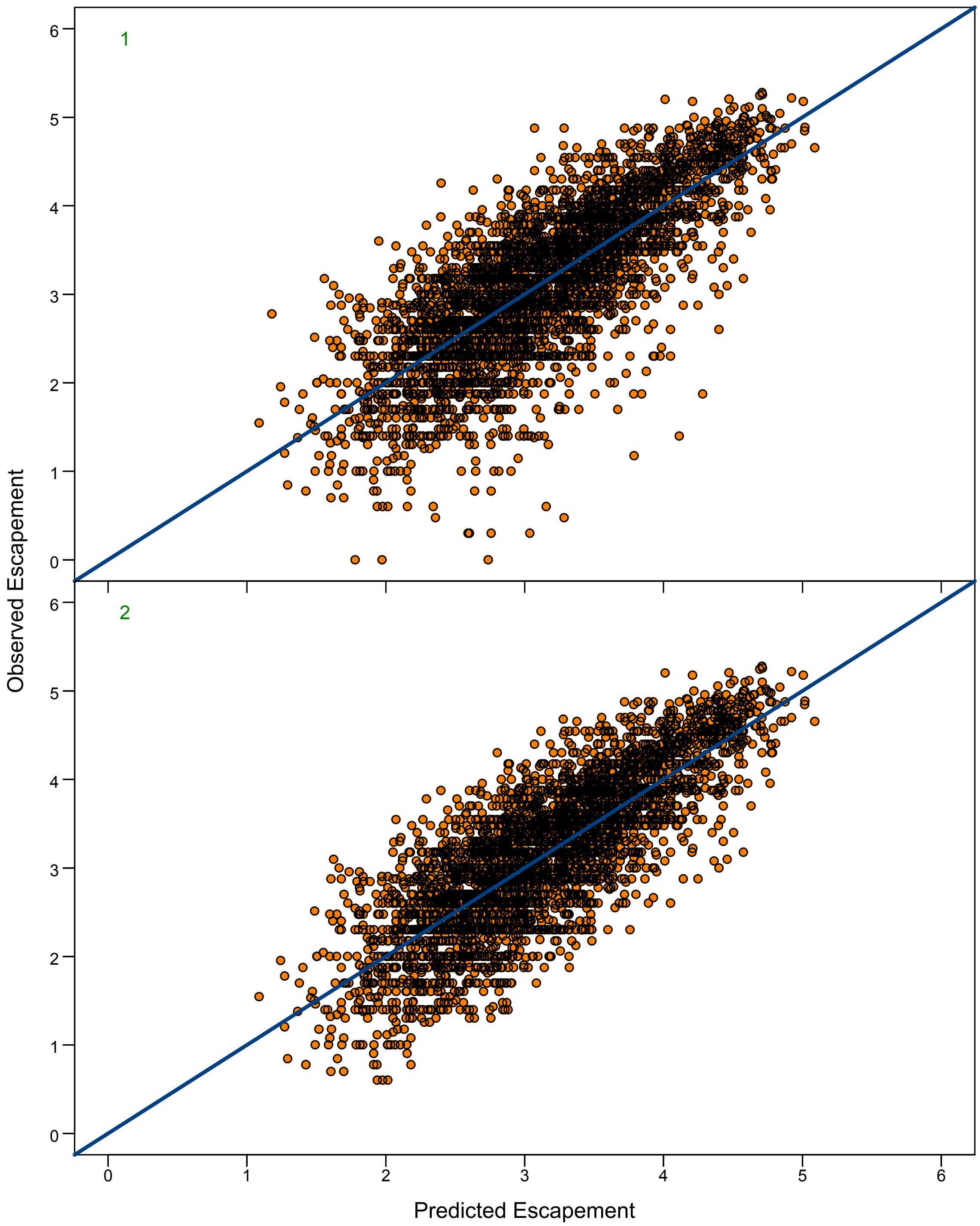

Figure 4. Observed wild escapement (vertical axis) versus predicted (horizontal axis) escapement in log base 10 using the developmental model with all observations (1, top panel, N=4515) and, without outliers (2, bottom panel, Model B, N=4454). The solid diagonal represents the 1:1 line.

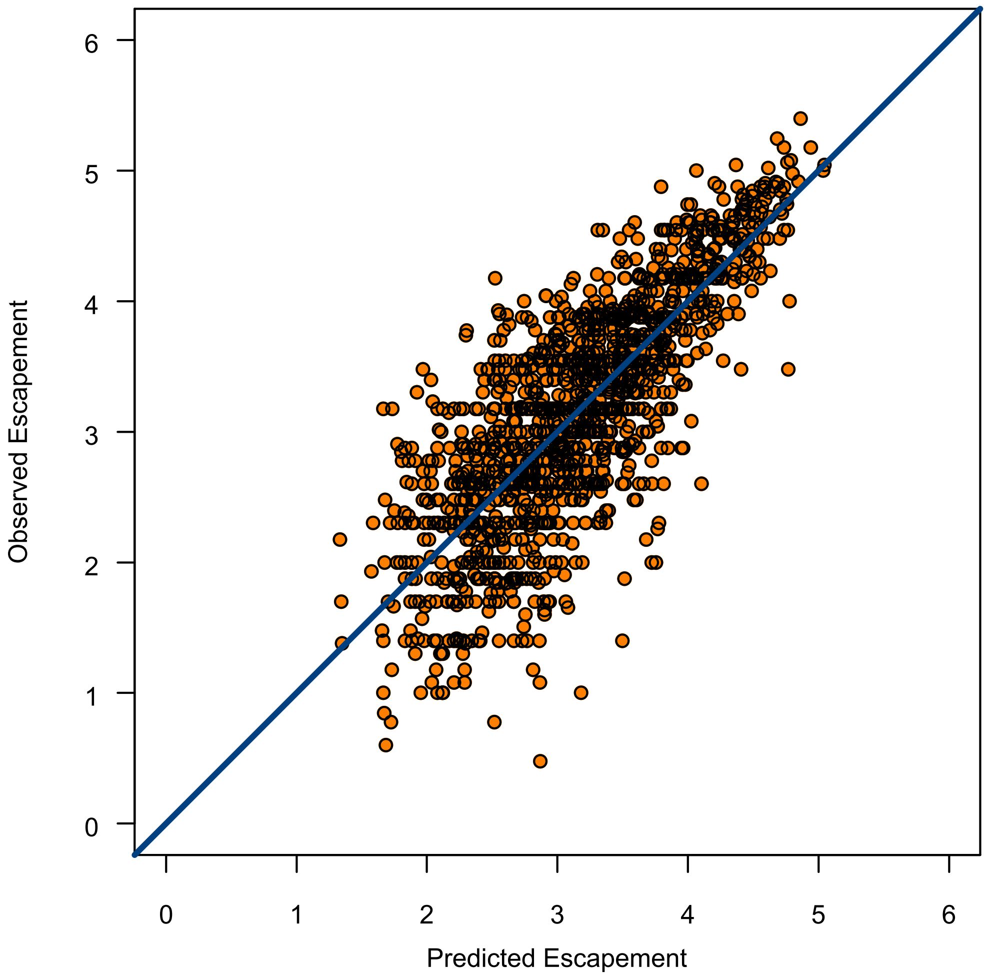

Figure 5. Validation of Model B using an independent data set (N=1522). Observed wild escapement (vertical axis) versus predicted (horizontal axis) escapement in log base 10.

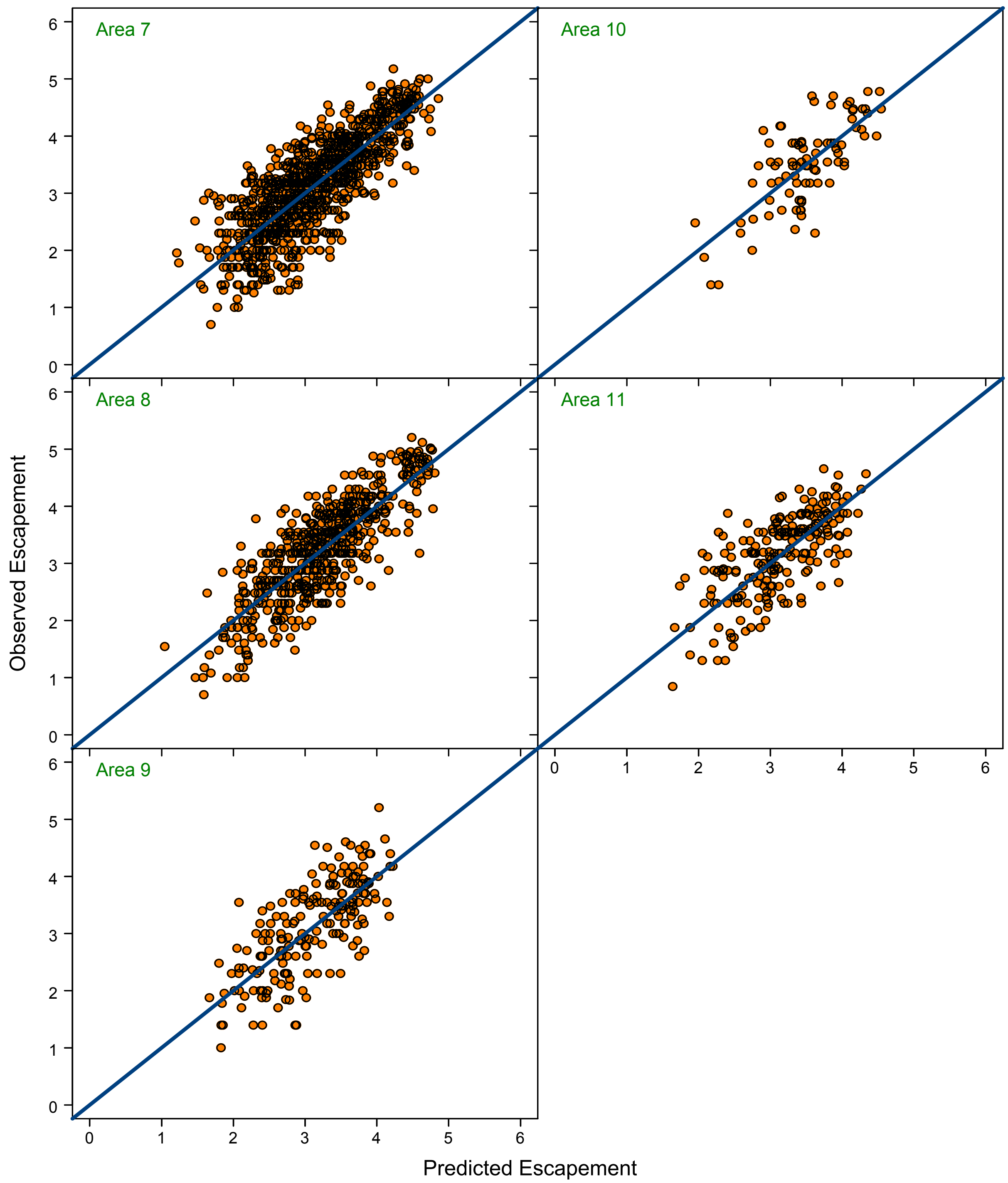

Figure 6. Model B fit for each of the areas. Observed wild escapement versus predicted wild escapement in log base 10.

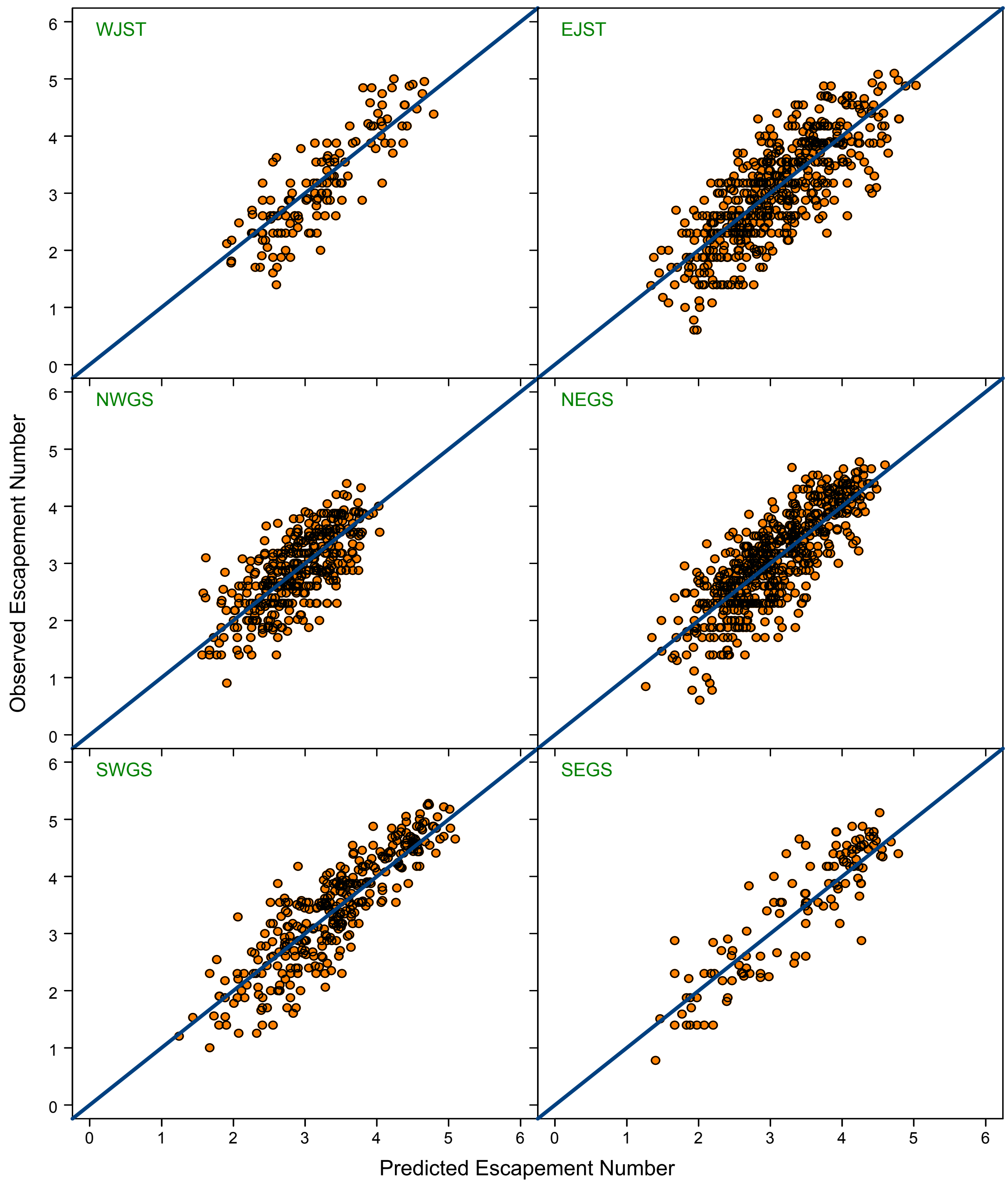

Figure 6. Continued

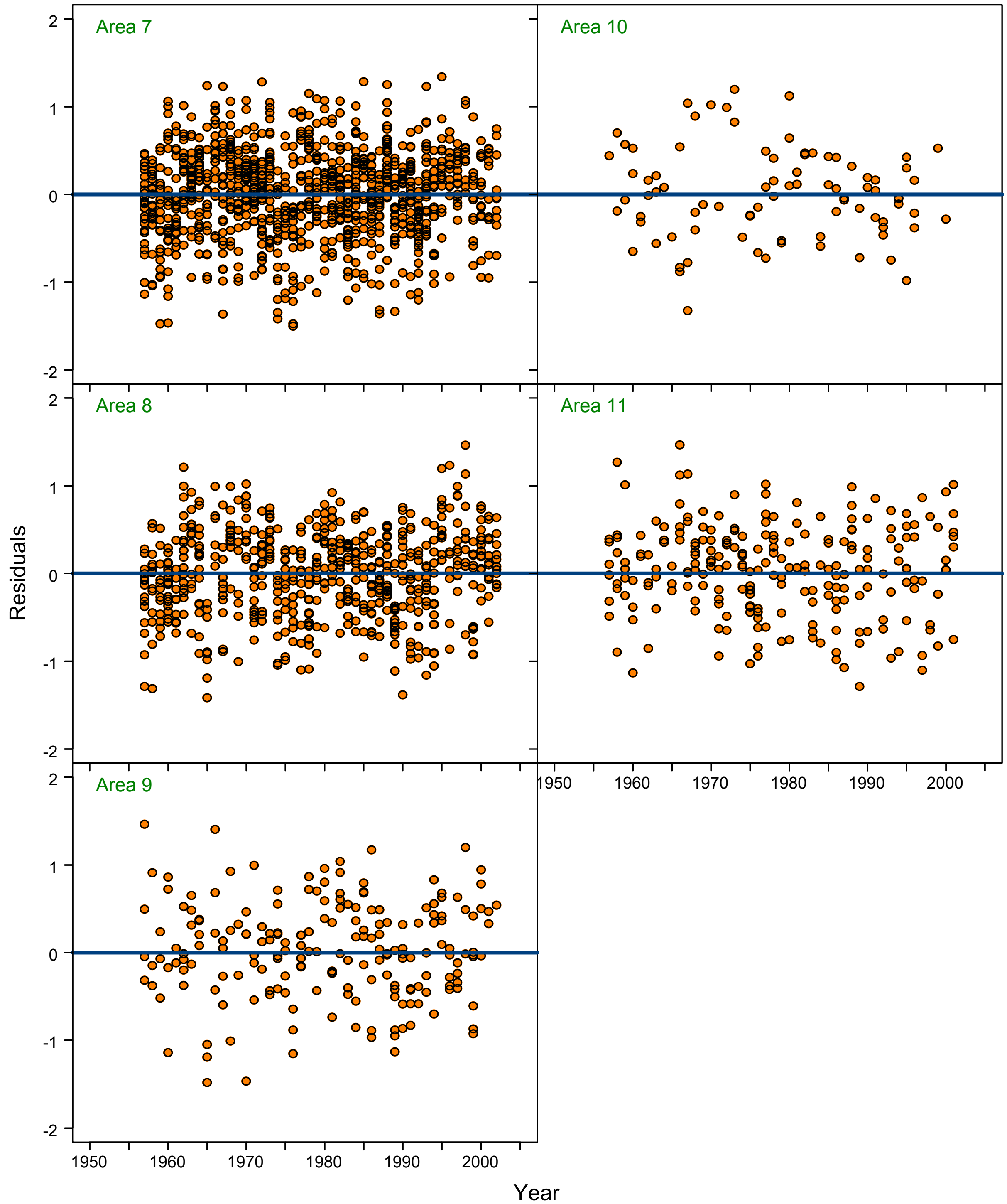

Figure 7. Plot of Model B's residuals against year per area.

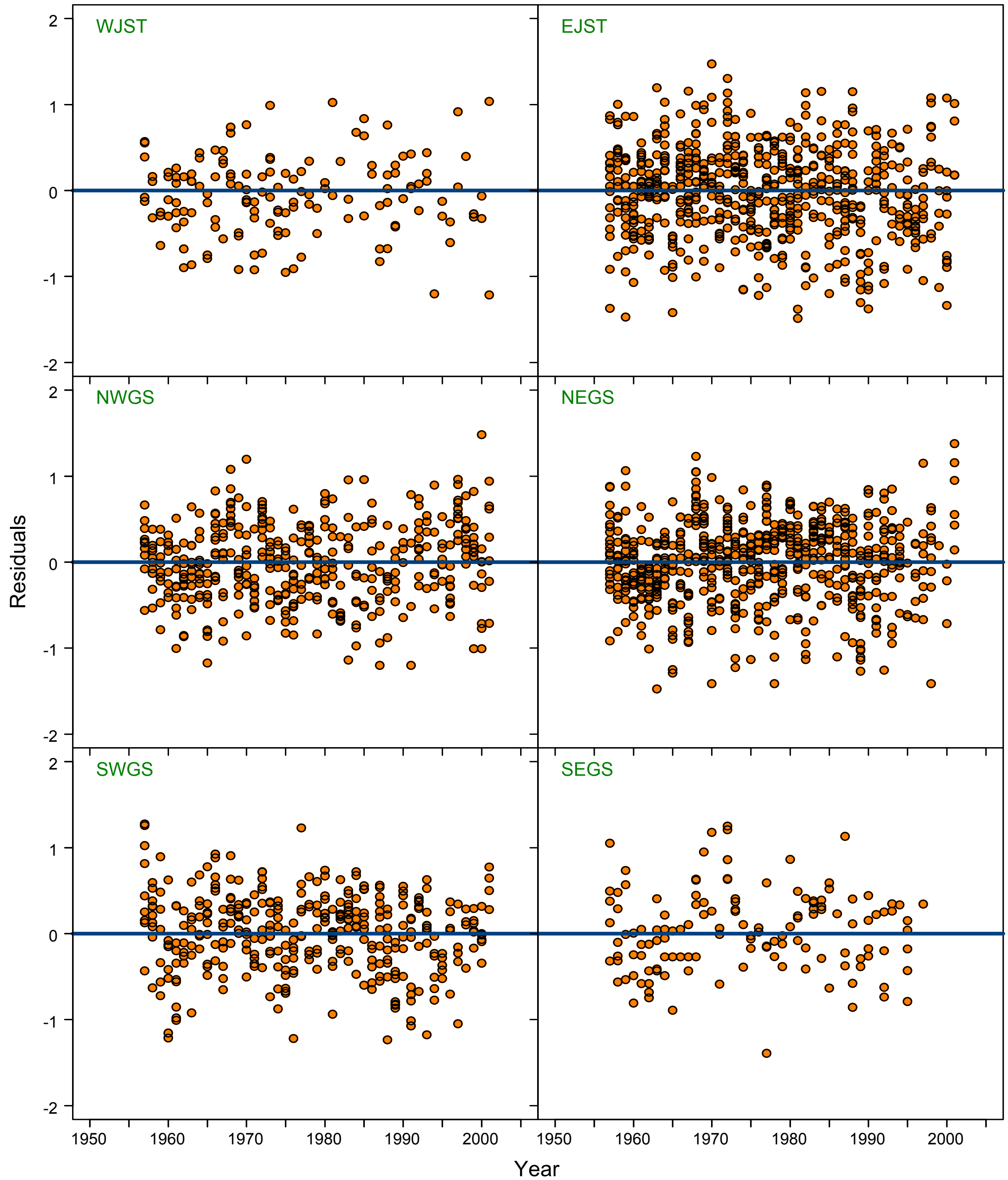

Figure 7. Continued.

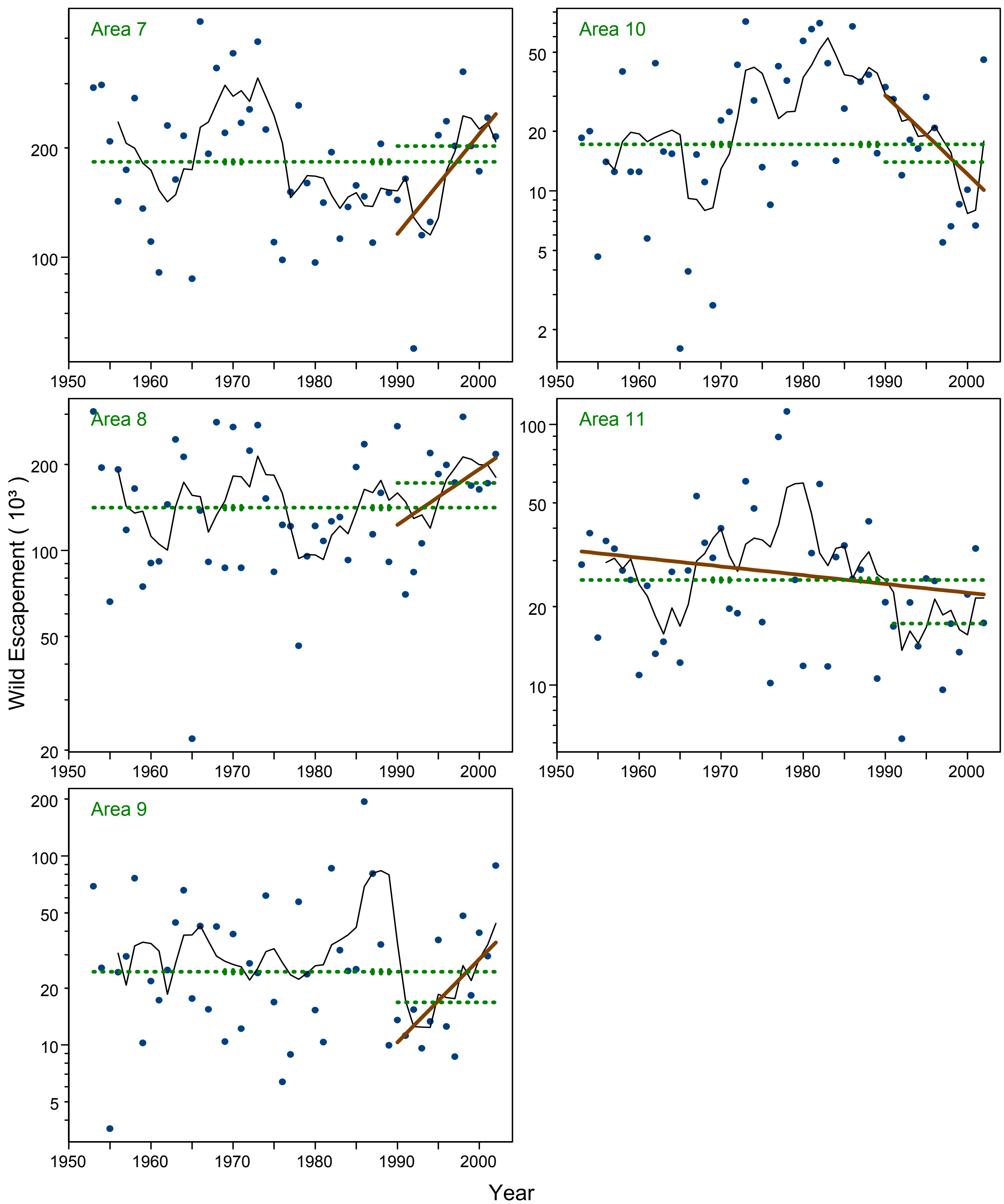

Figure 8. Time series of escapement estimates for wild chum salmon based on the "best data set". Points represent annual estimates and solid curved lines represent 1 generation (4 yr) smoothed average. Linear trends in the 4-year moving averages for the complete time series (solid, longer line) and for the last 3 generations (solid, shorter line) for each of the stock. The absence of a solid line indicates that the linear trend was not significant. Long term and last three generations median escapement (dotted lines).

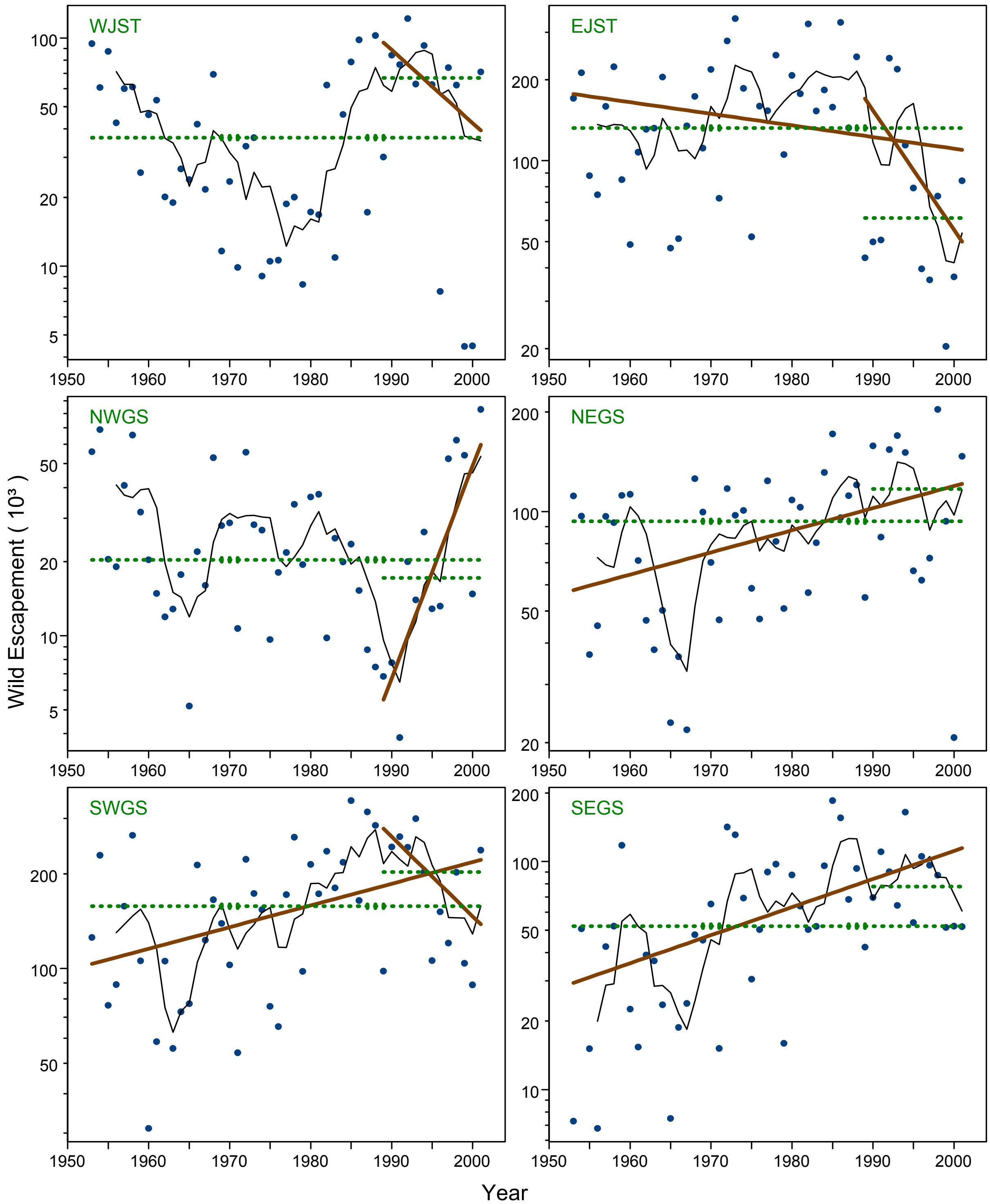

Figure 8. Continued

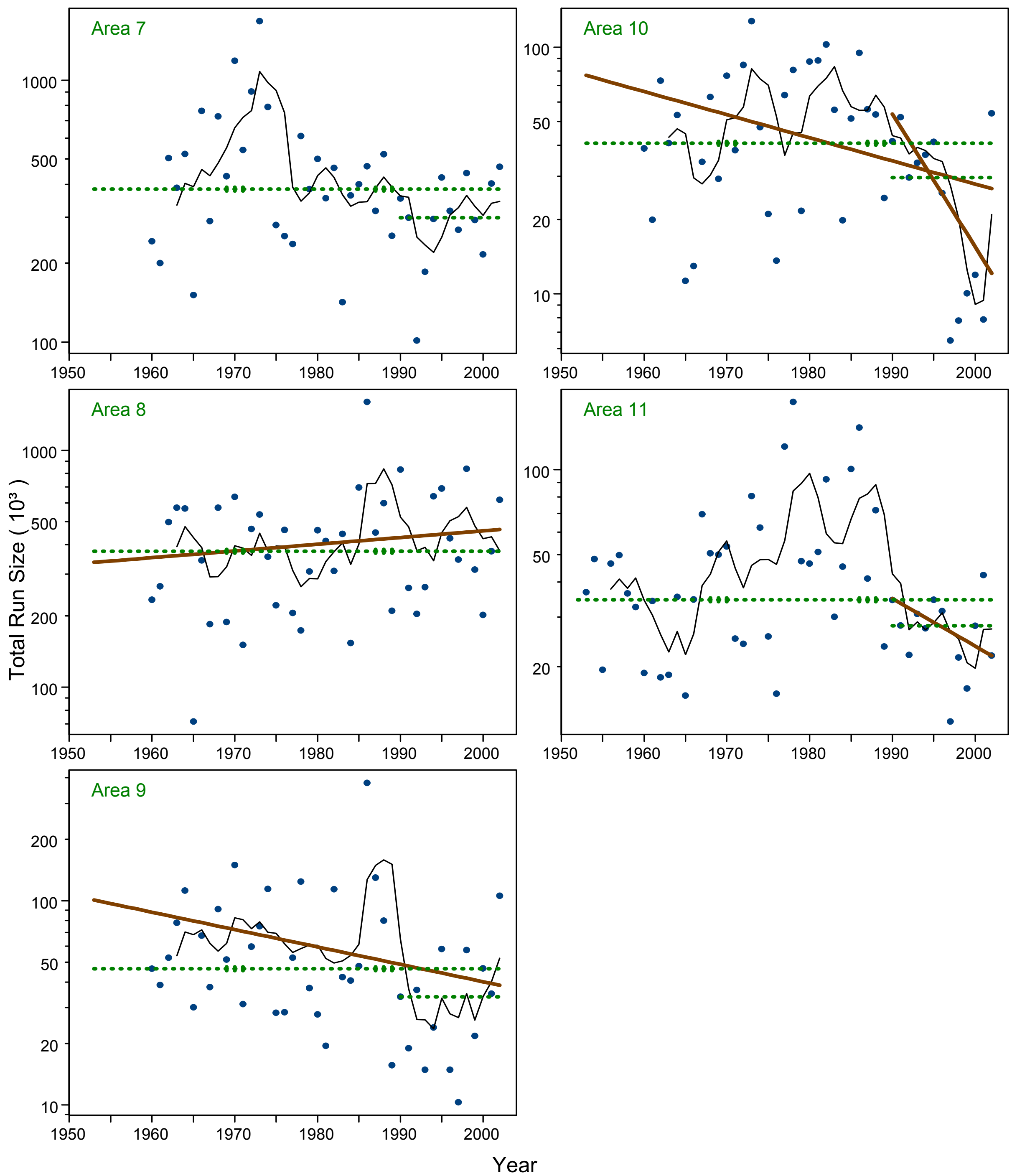

Figure 9. Time series of total run size (RS) estimates based on the “complete data set”. Dots represent annual estimates and solid curved lines represent 1 generation (4 yr) smoothed average. Linear trends in the 4-year moving averages for the complete time series (solid, longer line) and for the last 3 generations (solid, shorter line) for each of the stock. The absence of a solid line indicates that the linear trend was not significant. Long term and last three generations median escapement (dotted line).

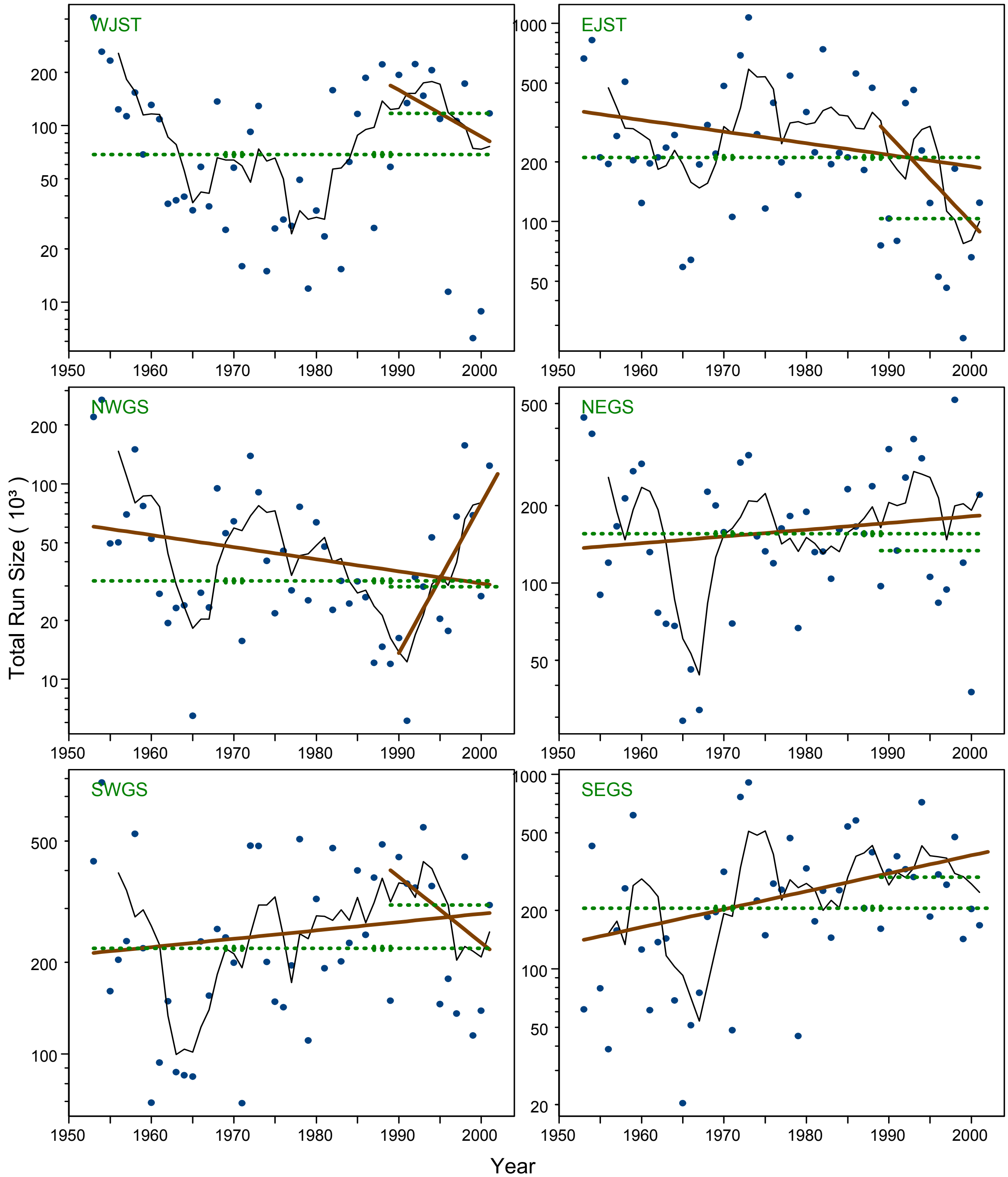

Figure 9. Continued

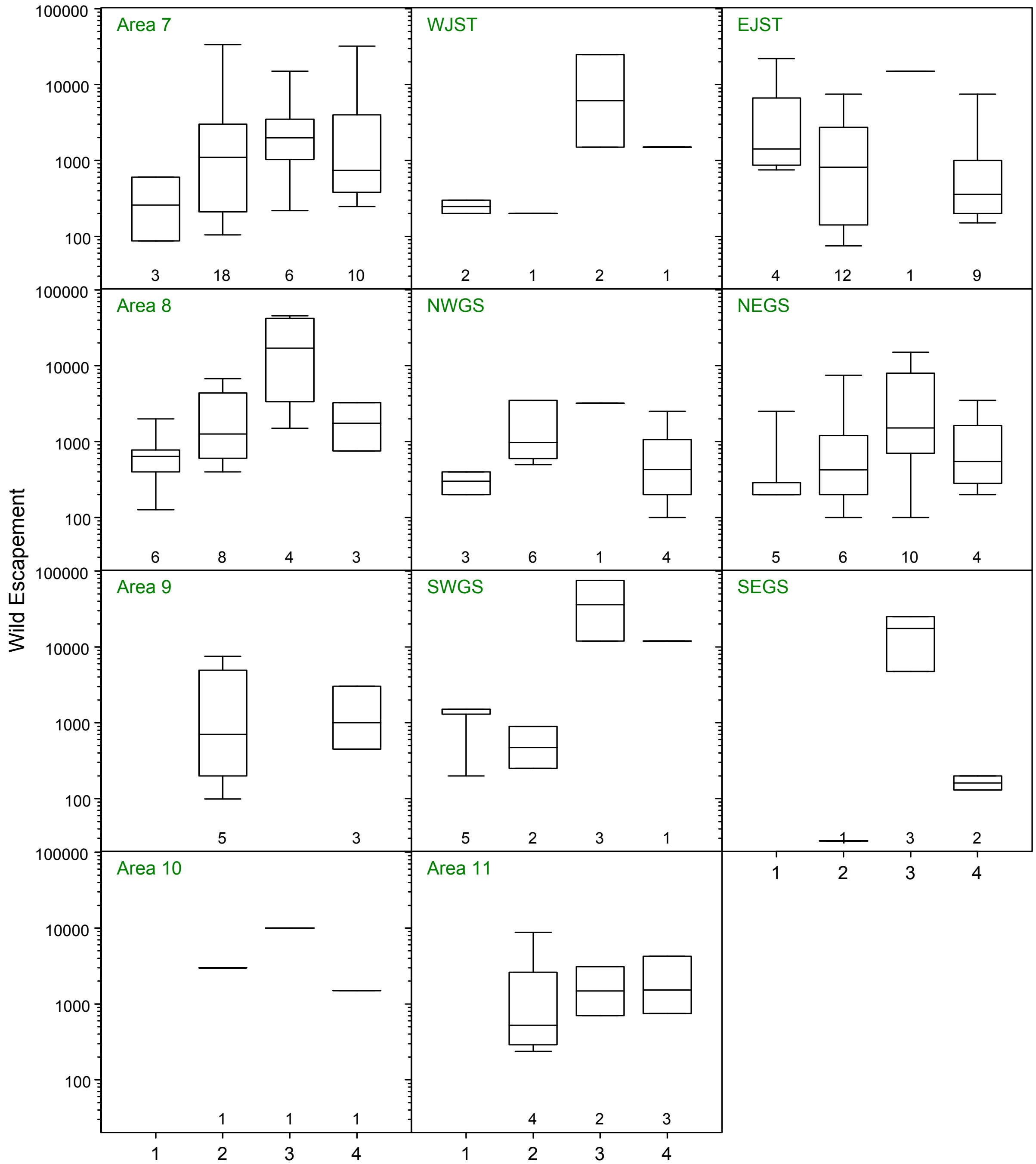

Figure 10A. Distribution of wild escapement estimates for streams with significant annual rates of change per year corresponding to: ≤ -5% (1), > -5% and < 0% (2), and ≥ 0% (3), plus those without significant trends (4). The horizontal line transecting each box indicates the median escapement, the bottom and top edges of each box correspond to the 25th and 75th percentiles, and the upper and lower limits of the vertical lines or whiskers are the minimum and maximum escapement recorded. The number of streams in each class is provided below each plot. A) complete time series, and B) last three generations.

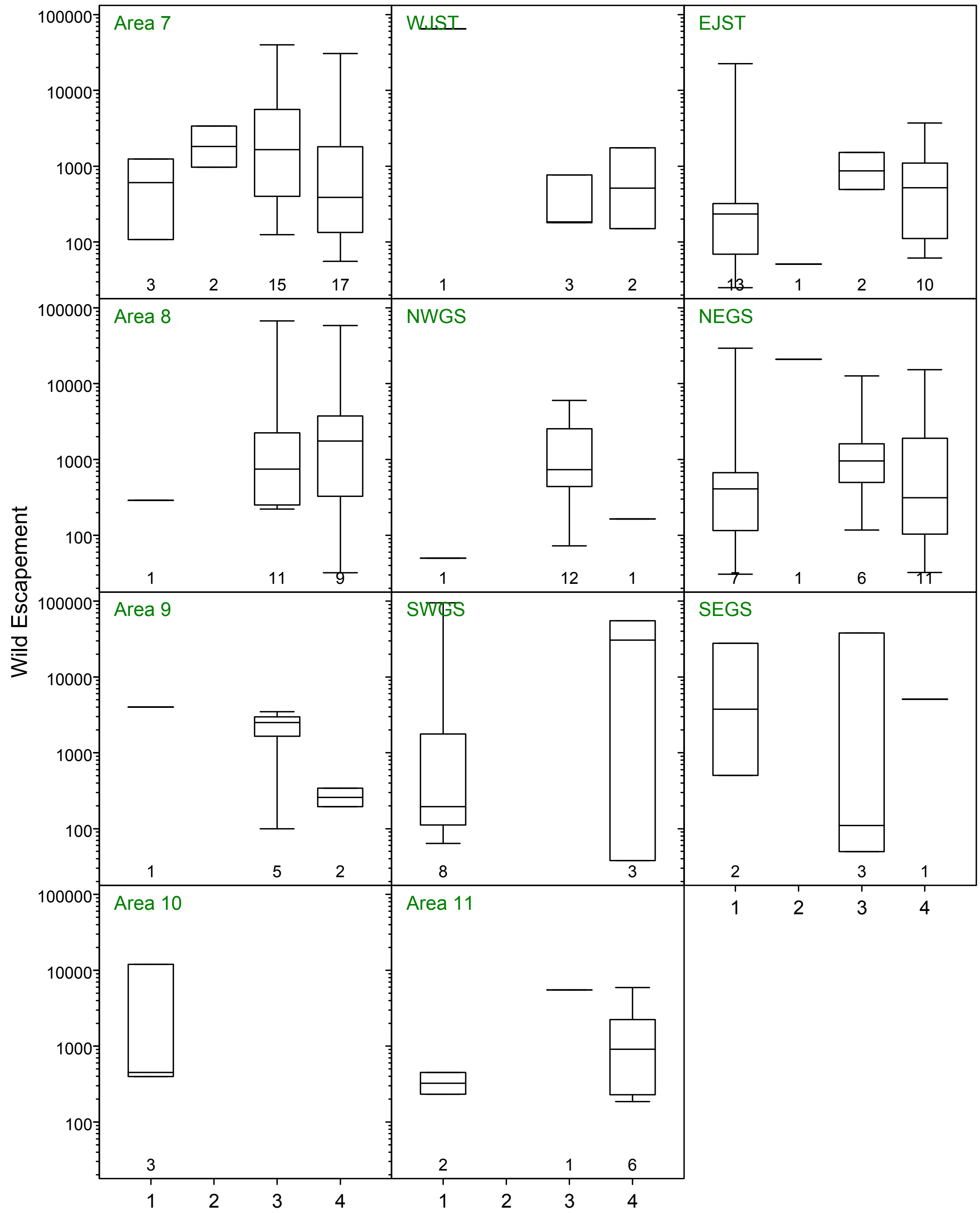

Figure 10B. Last 3 generations.

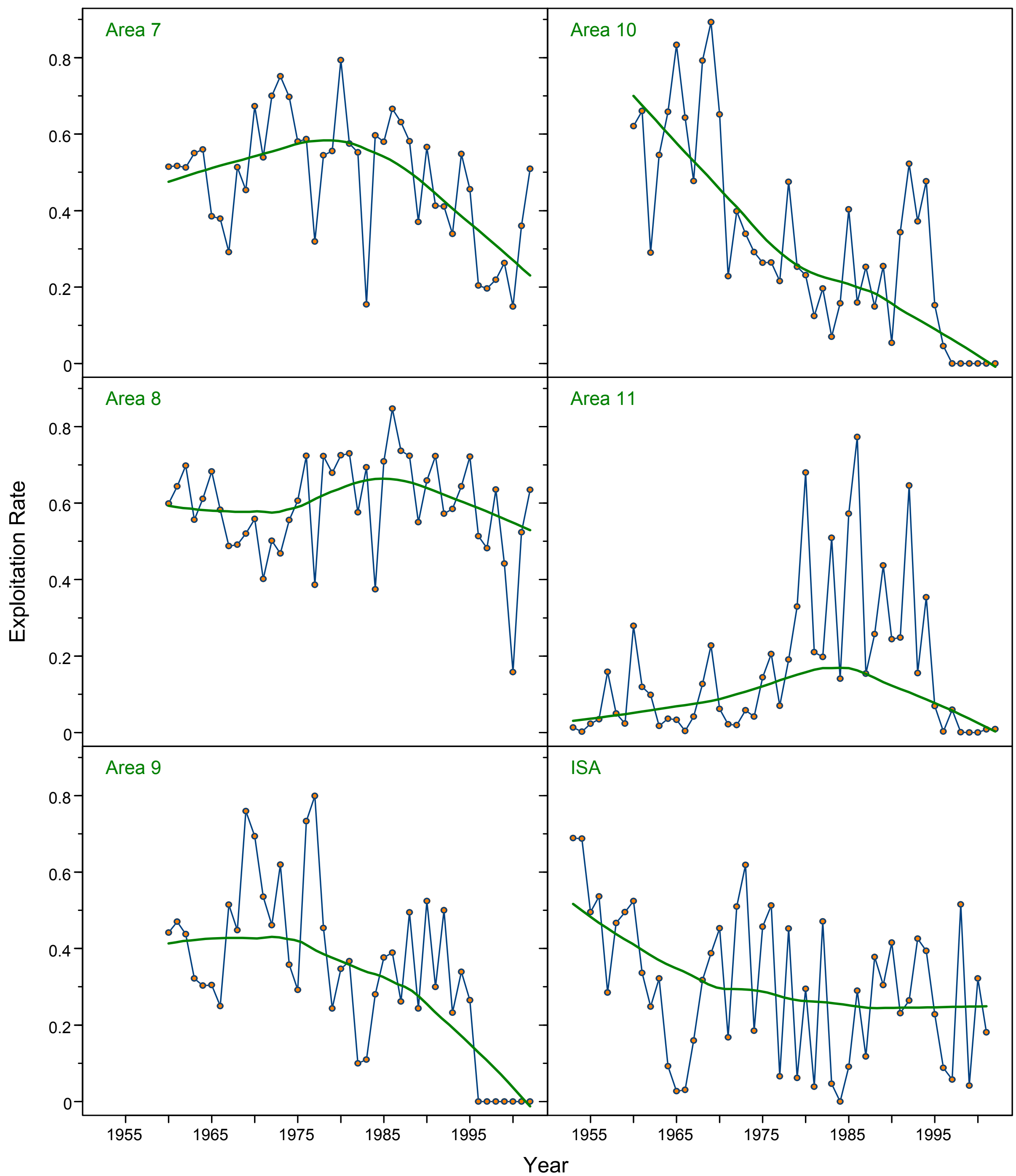

Figure 11. Annual exploitation rates for each stock. The smooth curve in each panel is a loess fit.

Appendix 1. List of 166 streams from the "Best data set". DFO statistical areas (Area), stream name (Name), NUSEDS Stream id (Str_id), and classes of relative rate of change in escapement for the complete time series (complete) and the last three generations (last3). Class 1: relative rate: ≤- 5%, class 2: > - 5% and < 0%, class 4:≥ 0%, and class=3: non significant relative rate of change in escapement.

AREA	NAME	Str_id	Complete	Last 3
Area 7	TANKEEAH RIVER	1001	1	4
Area 7	BIG BAY CREEK	1012	1	3
Area 7	MARY COVE CREEK	1830	1	3
Area 7	GOAT BUSHU CREEK	987	2	3
Area 7	WALKER LAKE CREEK	988	2	1
Area 7	CLATSE CREEK	989	2	3
Area 7	LEE CREEK	992	2	3
Area 7	BULLOCK CHANNEL #1 CREEK	995	2	3
Area 7	TOM BAY CREEK	1005	2	3
Area 7	NAMELESS CREEK	1006	2	3
Area 7	KAINET CREEK	1010	2	4
Area 7	BOLIN BAY CREEK	1016	2	4
Area 7	COOPER INLET #1 CREEK	1791	2	3
Area 7	KADJUSDIS RIVER	1800	2	3
Area 7	KUNSOOT RIVER	1801	2	3
Area 7	DEER PASS CREEK	1807	2	1
Area 7	KWAKUSDIS RIVER	1813	2	3
Area 7	WATSON BAY CREEK	1831	2	4
Area 7	BOTTLENECK CREEK	1832	2	3
Area 7	JAMES BAY CREEK	1833	2	4
Area 7	WINDY BAY CREEK	1837	2	3
Area 7	ROSCOE CREEK	991	3	4
Area 7	CHAMISS CREEK	998	3	4
Area 7	NEEKAS CREEK	999	3	3
Area 7	SALMON BAY CREEK	1007	3	2
Area 7	HIRD POINT CREEK	1008	3	3
Area 7	KORICH CREEK	1013	3	3
Area 7	POISON COVE CREEK	1014	3	1
Area 7	CARTER RIVER	1017	3	4
Area 7	BEALE'S LAGOON CREEK	1803	3	4
Area 7	BULLEY BAY CREEK	1816	3	2
Area 7	QUARTCHA CREEK	993	4	4
Area 7	LARD CREEK	1009	4	4
Area 7	MUSSEL RIVER	1015	4	4
Area 7	KITASU CREEK	1820	4	4
Area 7	CANYON CREEK	1834	4	4
Area 7	DUTHIE CREEK	1836	4	4
Area 8	KOEYE RIVER	957	1	4
Area 8	NOOTUM RIVER	960	1	3
Area 8	ASSEEK RIVER	964	1	3
Area 8	DEAN RIVER	975	1	4
Area 8	SKOWQUILTZ RIVER	978	1	4

Area 8	EUCOTT BAY CREEKS	982	1	4
Area 8	QUATLENA RIVER	961	2	4
Area 8	KWATNA RIVER	962	2	4
Area 8	NOOSESECK RIVER	973	2	4
Area 8	CASCADE RIVER	983	2	3
Area 8	SAGAR CREEK	1794	2	3
Area 8	EVANS INLET #3 CREEK	1795	2	1
Area 8	HOOK NOSE CREEK	1796	2	3
Area 8	JENNY BAY #3 CREEK	1798	2	3
Area 8	NECLEETSCONNAY RIVER	971	3	3
Area 8	GRANTHAM CREEK	976	3	4
Area 8	FRENCHMAN CREEK	985	3	4
Area 8	BELLA COOLA RIVER SYSTEM	968	4	4
Area 8	KIMSQUIT RIVER	977	4	3
Area 8	ELCHO CREEK	984	4	3
Area 8	MARTIN RIVER	986	4	4
Area 9	ALLARD CREEK	930	2	3
Area 9	WANNOCK RIVER	935	2	1
Area 9	CLYAK RIVER	949	2	4
Area 9	MILTON RIVER	952	2	4
Area 9	MACNAIR CREEK	953	2	3
Area 9	LOCKHART GORDON CREEK	929	3	4
Area 9	KILBELLA RIVER	947	3	4
Area 9	CHUCKWALLA RIVER	948	3	4
Area 10	TAKUSH RIVER	913	2	1
Area 10	WALKUM CREEK	917	3	1
Area 10	NEKITE RIVER	918	4	1
Area 11	WARNER BAY CREEK	895	2	1
Area 11	TAALTZ CREEK	896	2	4
Area 11	RAINBOW CREEK	899	2	3
Area 11	WAAMTX CREEK	903	2	3
Area 11	SEYMOUR RIVER	897	3	3
Area 11	JAP CREEK	906	3	1
Area 11	DRIFTWOOD CREEK	908	3	3
Area 11	WAUMP CREEK	905	4	3
Area 11	QUASHELLA RIVER	909	4	3
EJST	KAKWEIKEN RIVER	860	1	1
EJST	SHOAL HARBOUR CREEK	866	1	1
EJST	VINER SOUND CREEK	868	1	1
EJST	WAKEMAN RIVER	874	1	4
EJST	QUATAM RIVER	815	2	1
EJST	PHILLIPS RIVER	824	2	3
EJST	FRAZER CREEK	830	2	1
EJST	GLENDALE CREEK	847	2	3
EJST	AHTA RIVER	861	2	4
EJST	KINGCOME RIVER	872	2	3
EJST	MACKENZIE RIVER	876	2	1
EJST	ST. AUBYN CREEK	1126	2	3
EJST	CAMELEON HARBOUR CREEK	1127	2	1
EJST	THURSTON BAY CREEK	1128	2	3

EJST	WHITEROCK PASS CREEK	1130	2	2
EJST	VILLAGE BAY CREEK	1132	2	3
EJST	HOMATHKO RIVER	819	3	1
EJST	APPLE RIVER	828	3	1
EJST	HEYDON CREEK	831	3	3
EJST	WORTLEY CREEK	832	3	1
EJST	BIRD COVE CREEK	1129	3	3
EJST	WAIATT BAY CREEK	1131	3	3
EJST	OPEN BAY CREEK	1133	3	3
EJST	GRANITE BAY CREEK	1136	3	1
EJST	KANISH CREEK	1137	3	1
EJST	SOUTHGATE RIVER	817	4	1
NEGS	RUBY CREEK	764	1	4
NEGS	DEIGHTON CREEK	794	1	3
NEGS	THEODOSIA RIVER	800	1	4
NEGS	FORBES BAY CREEK	804	1	1
NEGS	BREM RIVER	813	1	3
NEGS	FROCK CREEK	-40006	2	3
NEGS	ANGUS CREEK	771	2	3
NEGS	SECHELT CREEK	774	2	1
NEGS	VANCOUVER RIVER	778	2	1
NEGS	BRITTAIN RIVER	784	2	3
NEGS	BISHOP CREEK	786	2	3
NEGS	SNAKE BAY CREEK	769	3	1
NEGS	LOIS RIVER	790	3	3
NEGS	OKEOVER CREEK	799	3	4
NEGS	PENDER HARBOUR CREEKS	7990607	3	3
NEGS	ALBION CREEK	-40005	4	4
NEGS	STORM BAY CREEK	-40004	4	1
NEGS	DORISTON CREEK	767	4	1
NEGS	TZOONIE RIVER	776	4	2
NEGS	DESERTED RIVER	780	4	1
NEGS	SKWAWKA RIVER	782	4	3
NEGS	JEFFERD CREEK	788	4	3
NEGS	WHITTALL CREEK	791	4	4
NEGS	LANG CREEK	792	4	3
NEGS	SLIAMMON CREEK	798	4	4
SEGS	LYNN CREEK	693	2	4
SEGS	SEYMOUR RIVER	691	3	1
SEGS	CAPILANO RIVER	697	3	4
SEGS	INDIAN RIVER	688	4	4
SEGS	MAMQUAM RIVER	709	4	3
SEGS	CHEAKAMUS RIVER	719	4	1
WJST	QUATSE RIVER	1106	1	3
WJST	CLUXEWE RIVER	1109	1	4
WJST	AMOR DE COSMOS CREEK	1123	2	4
WJST	HYACINTHE CREEK	1134	3	4
WJST	FULMORE RIVER	836	4	3
WJST	NIMPKISH RIVER	1112	4	1
NWGS	MENZIES CREEK	1139	1	1

NWGS	QUINSAM RIVER	1144	1	3
NWGS	WATERLOO CREEK	1171	1	4
NWGS	TSABLE RIVER	1166	2	4
NWGS	COWIE CREEK	1168	2	4
NWGS	WILFRED CREEK	1170	2	4
NWGS	ROSEWALL CREEK	1172	2	4
NWGS	MCNAUGHTON CREEK	1173	2	4
NWGS	ENGLISHMAN RIVER	1184	2	4
NWGS	OYSTER RIVER	1149	3	4
NWGS	TSOLUM RIVER	1157	3	4
NWGS	COOK CREEK	1174	3	4
NWGS	NILE CREEK	1178	3	4
NWGS	CAMPBELL RIVER	1141	4	4
SWGS	WALKERS CREEK	-400011	1	3
SWGS	BONELL CREEK	1187	1	1
SWGS	BUSH CREEK	1199	1	1
SWGS	HOLLAND CREEK	1201	1	1
SWGS	STOCKING CREEK	1202	1	1
SWGS	BONSALL CREEK	-400012	2	1
SWGS	NANOOSE CREEK	1186	2	1
SWGS	CHEMAINUS RIVER	1204	3	1
SWGS	NANAIMO RIVER	1194	4	3
SWGS	COWICHAN RIVER	1208	4	1
SWGS	GOLDSTREAM RIVER	1211	4	3