Temporal Trends in the Relative Abundance of New Zealand Freshwater Fishes

Analysis of New Zealand Freshwater Fish Database Records

Prepared for Ministry for the Environment

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Executive Summary

Without accounting for confounding factors in the New Zealand Freshwater Fish Database (NZFFD), there is too much noise in the dataset to accurately describe trends in the abundance of eels and other fish species. This is particularly problematic for environmental reporting purposes. NIWA has standardised the NZFFD and completed a temporal trend analysis of longfin eels, and the methods used are generally applicable to other fish species in the database. The objective of this study was to calculate and assess standardised trends in fish abundance from the NZFFD, which will improve the robustness and reliability of this database for reporting on fish stocks and changing trends over time. This information is needed by the Ministry for the Environment (MfE) to accurately characterise current condition in New Zealand freshwater fishes.

We used stepwise generalised linear models (GLM) to estimate the characteristic probability of capture attributable to each year of the record (probability of capture hereafter) for a selected group of species in the NFFFD, and several multi-species groups. Using probability of capture as an index of relative abundance rather than raw presence/absence data from the NZFFD reduced the influence of confounding variables (e.g., sampling method) on temporal trends. A Sen Slope Estimator (SSE) was used to simplify the complex temporal variability in probability of capture into straight lines.

Two approaches were used to calculate SSE for each species: an established approach that uses probability of capture values only (SSE), and a new approach that uses probability of capture values weighted by the inverse of the sum of the confidence intervals (CI) of the probability of capture values (WSSE). In the WSSE, pairs of years that collectively have small CIs are weighted more heavily than pairs of years that collectively have large CIs because we were more confident in these probability of capture values. Further testing is required before we can be confident that the WSSE is a better descriptor of trends than the SSE, therefore we provide both WSSE and the SSE calculations in the present study. As requested by MfE, we provide both SSE and WSSE results for each of three time periods: 1977–2015, 1977–1994 and 1995–2015. A total of 78 Sen slopes (both SSE and WSSE) were calculated for 13 species for each of three time periods. Results for the remaining 18 fishes were unreliable because we encountered difficulties with model overfitting when calculating probability of capture values.

From the 78 Sen slopes, 35 % (n=27) corresponded to decreasing trends, 28% corresponded to increasing trends, and the remainder were indeterminate. The average (±95 % CI) magnitude of the decreasing trends was 0.38 (± 0.12) %/year. The average (±95 % CI) magnitude of the increasing trends was 0.27 (± 0.05) %/year. Brown trout, Canterbury galaxias and shortfin eel were the only species for which trend directions were consistent across the three time periods. For brown trout and Canterbury galaxias decreasing trends occurred in each time period; for shortfin eels, increasing trends occurred in each time period.

The present study provides information on the direction and magnitude of trends in the relative abundance of freshwater fish species, but it does not consider or discuss the ecological or management implications of the trends. Assessing ecological or management implications of the trends would require the socioecological values supported by the fishes to be clearly defined, and an understanding of the pressures structuring the populations. Future assessments of the causes and management implications of trends in freshwater fishes are likely to become more pressing in New Zealand given that the high proportion of native freshwater fishes classified as 'Threatened' or 'At Risk' has recently increased under the current New Zealand Threat Classification System.

1   Introduction

As part of the Environmental Reporting Act 2015, the Crown requires regular reports on New Zealand's environment[1]. The Government Statistician and the Secretary for the Environment have responsibility for this Act and the reporting structure has been divided into five domains: air, atmosphere and climate, land, fresh water and marine. The freshwater domain comprises fresh water in all its physical forms and reporting involves characterising the biophysical condition of all freshwater environments and how this has varied over time. The state of New Zealand's freshwater fishes are included in the freshwater domain reporting because they have high cultural, commercial, recreational and intrinsic biodiversity value. To assist the Ministry for the Environment (MfE) in accurately reporting the current condition of freshwater fishes, we calculated and assessed temporal trends in the abundance of 31 species and multi-species groups.

The New Zealand Freshwater Fish Database (NZFFD) (McDowall and Richardson 1983) contains the longest time-series of information on freshwater fish occurrence in New Zealand. The NZFFD contains 35,000 freshwater fish observations from across New Zealand and observations date back to 1901 (Figure 1-1). The NZFFD is an open resource where anyone can input and download data. Research institutes, universities, anglers, government organisations and community interest groups are frequent contributors. The minimum data available from each NZFFD observation are sampling method, location, date, and descriptors of the presence or absence of fishes. Data in the NZFFD have previously been used to identify drivers of fish spatial distributions and predict species occurrence (Joy and Death 2004; Leathwick, Elith et al. 2008; Leathwick, Julian et al. 2008; Crow, Booker et al. 2014).

Differences in sampling methodology between NZFFD observations may generate variability in catches between years. Catch rates such as abundance (no./m^2) or occurrence (presence/absence) are influenced by methodological and environmental conditions because different fish species have different habitat preferences and respond differently to various sampling methods. Unfortunately, the environmental conditions and sampling methodology recorded on NZFFD observations are not consistent through time, which causes temporal variation in catch rates (e.g., probability of capture). For example, a recent analysis showed that there was a declining trend in an index of longfin habitat quality being sampled by NZFFD observers (NIWA, unpubl. data), which was associated with a reduction in longfin catch rates over time. This temporal confounding in habitat quality being sampled makes it difficult to determine if the reduction in longfin catch rates was associated with reduced longfin abundance in the wild or simply a reduction in the habitat quality being sampled. Temporal confounding in any spatial, methodological, and environmental variables is problematic for the Ministry for the Environment (MfE), who wish to use the NZFFD to examine temporal changes in the state of New Zealand's freshwater fishes. A recent analysis of temporal trends in eel abundance accounted for differences in sampling methodology and environmental conditions through time (Crow and Dunn 2013), but the same methodology has not been applied for other freshwater fishes. The present study provides information on temporal trends of New Zealand freshwater fishes for freshwater domain reporting being completed by MfE.

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[1] http://www.legislation.govt.nz/act/public/2015/0087/latest/DLM5941110.html

Figure 1-1: Locations of all NZFFD observations collected from 1901–2015.

1.1 Scope of this report

Without accounting for confounding factors in the New Zealand Freshwater Fish Database (NZFFD), there is too much noise in the dataset to accurately describe trends in the abundance of eels and other fish species. This is particularly problematic for environmental reporting purposes. NIWA has standardised the NZFFD and completed a temporal trend analysis of longfin eels, and the methods used are generally applicable to other fish species in the database. The primary objective of this study was to calculate and assess standardised trends in fish abundance from the NZFFD, which will improve the robustness and reliability of this database for reporting on fish stocks and changing trends over time. This information is needed by the Ministry for the Environment (MfE) to accurately characterise current condition in New Zealand freshwater fishes.

We used stepwise generalised linear models (GLM) to estimate the characteristic probability of capture attributable to each year of the record (probability of capture hereafter) for a selected group of species in the NFFFD, and several multi-species groups. Using probability of capture as an index of relative abundance rather than raw presence/absence data from the NZFFD reduced the influence of confounding variables (e.g., sampling method) on temporal trends. A Sen Slope Estimator (SSE) was used to simplify the complex temporal variability in probability of capture into straight lines.

As requested by MfE, we estimated trends with two different statistical approaches, a well-established approach that uses unweighted slopes and a new approach that uses weighted slopes. Both approaches were applied to data from three different time periods, 1977–2015, 1977–1994 and 1995–2015.

2   Methods

2.1   New Zealand Freshwater Fish Database (NZFFD)

2.1.1   Quality-Control Checks on NZFFD Observations

Administrators of the NZFFD (http://www.niwa.co.nz/our-services/online-services/freshwater-fish-database) carry out quality-control checks on each NZFFD observation to ensure the data are robust. Each NZFFD observation is a single entry submitted to the database that contains information on the sampling date, sampling methodology and fish species observed. NZFFD observations are first entered into the database through a pre-defined data and then submitted to the NZFFD administrator for approval. The NZFFD observations are checked to ensure that information from all environmental data fields are complete (e.g., % of habitat categories adds to 100%), fish identifications are correct (e.g., the species recorded on the observation are from their known distributional ranges), and that the NZFFD record has been appropriately matched to an individual segment of the national digital river network that provides the spatial framework for the River Environment Classification (REC1 and REC2[2]; Snelder and Biggs 2002).

The REC is based on a digital drainage network that was derived from a digital elevation model (DEM) with a spatial resolution of 50 m (Snelder and Biggs 2002). The river network and catchment boundaries were derived from a digital elevation model (DEM) with a spatial resolution of 50 m. The digital network represents New Zealand's rivers as ~ 600,000 segments (bounded by upstream and downstream confluences) and their corresponding catchments. The digital network is stored in a geodatabase that applies a unique identifier to each segment (NZSegment). The georeferenced segments and catchments facilitate analyses of upstream–downstream connectivity and accumulation of catchment characteristics (e.g., land areas having different geological or land cover categories) in the downstream direction. Assignments of NZSegments to the sampling coordinates of NZFFD observations are manually checked to identify and correct errors that periodically occur when NZSegments are automatically assigned to NZFFD observations using straight line distances between the recorded site coordinates and the NZSegment coordinates (see Crow et al., 2014 for details). After these checks are completed by the NZFFD administration team, the NZFFD observation is made publically available through the NZFFD homepage.

2.1.2   Generating Presence/Absence Data for Freshwater Fishes

The NZFFD was used to generate a national-scale dataset of presence and absence of New Zealand freshwater fishes. We inspected 35,306 NZFFD observations available at 9 March 2016 and omitted any NZFFD observations collected from areas that were not connected to a river network (e.g., water races) or were in lentic water bodies. To ensure that there was sufficient replication of NZFFD observations available for each year, we only included data from 1977–2015. Very few NZFFD observations were available for each year from 1901–1977 and in 2016, which would have generated misleading results for these years. The final dataset contained 26,915 NZFFD observations, which was approximately 76% of all records in the NZFFD[3].

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[2] https://www.niwa.co.nz/freshwater-and-estuaries/management-tools/river-environment-classification-0
[3] The percentage estimate of 76% was calculated in relation to all NZFFD records. This percentage would have been higher if it was expressed as a proportion of NZFFD records not assigned to lakes, wetlands or single digit NZSegments.

To ensure sufficient levels of replication for each fish species, we only analysed species for which presence was recorded at more than 30 different NZSegments across the entire time series (sensu Leathwick, Elith et al. 2008; Leathwick, Julian et al. 2008; Crow, Booker et al. 2014).

We only included taxa that were identified to species level, with the exception of freshwater crayfish (kōura). Although kōura are identified in the NZFFD at the genus level, they were included because they support cultural, commercial, recreational and intrinsic biodiversity values. We only included taxa for which current species descriptions are available, with the exception of three recently discovered *Galaxias* taxa (*G*. 'species D', *G*. 'northern', *G*. 'southern') that are awaiting description because they are genetically and morphologically distinct (referred to as evolutionary significant units) (Waters and Wallis 2001a; Waters and Wallis 2001b). Species in the Mugilidae family were excluded because they are predominantly occupy marine and estuarine habitats. Fishes belonging to the families Tripterygiidae and Pleuronectidae were also excluded because most species occur in estuarine habitats, with the exception of *Rhombosolea retiaria* (black flounder). *R. retiaria* was included because it predominantly occurs in fresh water (McDowall 1990). We only included non-diadromous fishes (i.e., fishes that do not undergo migrations between fresh and sea water) if spatial data were available on the catchments or sub-catchments in which the species is known to occur. Data on the spatial extent of non-diadromous species distributions were used to ensure that predictive models only used information from within species ranges.

NZFFD observations that met all of the criteria listed above were used to generate presence/absence data for 31 species, for each NZFFD observation (Table 2-1). Assigning a species as either present or absent for each NZFFD observation assumed that if the species was not recorded on the observation it had not been observed during the sampling (i.e., true absence at the time of sampling). The presence or absence of any native and any exotic species was also calculated from the NZFFD observations, based on the species 'Status' as listed in Table 2-1. The term 'native fish' hereafter refers to the presence of at least one native fish from an NZFFD observation. The term 'exotic fish' hereafter refers to the presence of at least one exotic fish from an NZFFD observation. Hereafter, we use the term 'species' to refer to all taxa described to species level, kōura at the genus level, presence of any native species (i.e., native fish) and presence of any exotic species (i.e., exotic fish).

Table 2-1: **Species list used to examine temporal trends in freshwater fish relative abundance from NZFFD observations from 1977 to 2015.** Life-history classes are based on McDowall (1990) and McDowall (2010). Species are ordered from the highest to lowest number of total NZFFD observations where a species was recorded as present (Present).

NZFFD code	Scientific name	Common name	Life history	Status	Present	Absent
angdie	*Anguilla dieffenbachii*	Longfin eel	Diadromous	Native	9690	17225
saltru	*Salmo trutta*	Brown trout	Non-diadromous	Exotic	7070	19845
parane	*Paranephrops* spp.	Kōura	Non-diadromous	Native	4753	22162
angaus	*Anguilla australis*	Shortfin eel	Diadromous	Native	4324	22591
gobbre	*Gobiomorphus breviceps*	Upland bully	Non-diadromous	Native	3794	23121
gobcot	*Gobiomorphus cotidianus*	Common bully	Diadromous	Native	3656	23259
gobhut	*Gobiomorphus huttoni*	Redfin bully	Diadromous	Native	3454	23461
galmac	*Galaxias maculatus*	Īnanga	Diadromous	Native	2621	24294
galfas	*Galaxias fasciatus*	Banded kōkopu	Diadromous	Native	2572	24343
galbre	*Galaxias brevipinnis*	Kōaro	Diadromous	Native	2241	24674
chefos	*Cheimarrichthys fosteri*	Torrentfish	Diadromous	Native	2069	24846
oncmyk	*Oncorhynchus mykiss*	Rainbow trout	Non-diadromous	Exotic	1675	25240
galvul	*Galaxias vulgaris*	Canterbury galaxias	Non-diadromous	Native	1424	25491
retret	*Retropinna retropinna*	Common smelt	Diadromous	Native	1035	25880
gobbas	*Gobiomorphus basalis*	Cran's bully	Non-diadromous	Native	940	25975
gobhub	*Gobiomorphus hubbsi*	Bluegill bully	Diadromous	Native	926	25989
galpau	*Galaxias paucispondylus*	Alpine galaxias	Non-diadromous	Native	704	26211
galpos	*Galaxias postvectis*	Shortjaw kōkopu	Diadromous	Native	595	26320
galarg	*Galaxias argenteus*	Giant kōkopu	Diadromous	Native	585	26330
gamaff	*Gambusia affinis*	Gambusia	Non-diadromous	Exotic	550	26365
galdiv	*Galaxias divergens*	Dwarf galaxias	Non-diadromous	Native	529	26386
geoaus	*Geotria australis*	Lamprey	Diadromous	Native	502	26413
gobgob	*Gobiomorphus gobioides*	Giant bully	Diadromous	Native	395	26520
caraur	*Carassius auratus*	Goldfish	Non-diadromous	Exotic	286	26629
galspd	*Galaxias* "species D"	Galaxias "species D"	Non-diadromous	Native	272	26643
galgol	*Galaxias gollumoides*	Gollum galaxias	Non-diadromous	Native	270	26645
onctsh	*Oncorhynchus tshawytscha*	Chinook salmon	Diadromous	Exotic	267	26648
salfon	*Salvelinus fontinalis*	Brook char	Non-diadromous	Exotic	196	26719
rhoret	*Rhombosolea retiaria*	Black flounder	Diadromous	Native	190	26725
galpro	*Galaxias prognathus*	Upland longjaw galaxias	Non-diadromous	Native	160	26755
galspn	*Galaxias* "northern"	Galaxias "northern"	Non-diadromous	Native	144	26771
-	-	Native Fish	-	Native	20585	6330
-	-	Exotic fish	-	Exotic	9751	17164

2.2 Predictors of Species Occurrence

A suite of environmental, spatial, hydrological and methodological predictor variables was used to explain variation in species occurrence. Values of the predictor variables were extracted from the NZFFD observation or from the environmental data associated with the NZSegment assigned to the NZFFD observation. Predictors were selected based on the results of previous studies, which used a subset of the predictor variables in the present study to explain up to 90% of the variation in freshwater fish species occurrence in the NZFFD (Leathwick, Elith et al. 2008; Leathwick, Julian et al. 2008; Crow, Booker et al. 2014). The methodological predictors were selected based on a study by Crow and Dunn (2013), who found that sampling methods explained the largest amount of variation in species occurrence of longfin eels (*A. dieffenbachii*). We provide an overview and ecological justification for including each of these predictor variables in Sections 2.2.1–2.2.4.

2.2.1 Environmental Predictors

The REC2 data were used to obtain information for 40 environmental predictors based on the upstream and catchment-scale predictors outlined in Table 4 of Leathwick et al. (2008), and all non-hydrological predictors outlined in Table 3 of Leathwick et al. (2008) for each NZFFD observation. In addition to the 40 environmental predictors from Leathwick et al., (2008), we included a further five environmental predictors. We extracted information from the REC2 on within-segment measures of slope (i.e., Segslpmax and Segslpmean) for each NZFFD observation. Within-segment slope data were included as predictors because stream slope characteristics are some of the most important predictors of freshwater fish occurrence in the NZFFD (Leathwick, Elith et al. 2008; Leathwick, Julian et al. 2008; Crow, Booker et al. 2014). Information on sinuosity (Sinuosity) was extracted from the REC2 for each NZFFD observation, because this predictor is a descriptor of habitat diversity. Information on the distance to the headwaters (Headwater Distance) and stream order (Stream Order) were extracted from the REC2 for each NZFFD observation, because these predictors reflected stream size and distance from the water source. The final environmental dataset included 45 potential predictors which, at a minimum, reflected the same environmental information for each NZFFD observation that has been used to predict species occurrence throughout New Zealand by other researchers (Joy and Death 2004; Leathwick, Elith et al. 2008; Leathwick, Julian et al. 2008; Crow, Booker et al. 2014). Abbreviations and descriptions of the environmental predictors are in Table 2-2.

2.2.2 Spatial Predictors

The REC2 data were used to obtain easting and northing NZTM coordinates for each NZFFD observation. These coordinates were extracted from the downstream end of the NZSegment assigned to each NZFFD observation. Coordinates were then used to calculate a two dimensional matrix of x (Easting) and y (Northing) geographical coordinates for each NZFFD observation based on the cubic trend surface regression formula suggested by Legendre (1990) (also see Legendre and Legendre 1998). The spatial matrix contained the raw NZTM coordinates (i.e., x and y only), multiples of the raw coordinates (i.e., x × y) and the squared and cubic terms of x, y and x × y coordinates. The variables in the spatial matrix were used as predictors because some New Zealand freshwater fish species have restricted spatial distributions and biogeographical patterns (Leathwick, Elith et al. 2008; McDowall 2010; Crow, Booker et al. 2014). Abbreviations and descriptions of the spatial predictors are in Table 2-2.

2.2.3   Hydrological Predictors

REC2 data were used to extract information for 34 predictors that describe the hydrological regime at the NZSegment corresponding to each NZFFD observation. The hydrology predictors in the REC2 (Snelder and Booker 2013) were used in the present study because they have previously been shown to explain statistically significant amounts of variation in fish presence from NZFFD observations (Crow, Booker et al. 2013; Crow, Booker et al. 2014). Abbreviations and descriptions of the hydrological predictors are in Table 2-2.

2.2.4   Methodological Predictors

We used three predictors that characterised the sampling characteristics associated with each NZFFD observation. Crow and Dunn (2013) showed that information relating to fishing method, regional location, organisation the observer worked for, unique observer identification number and location of the NZFFD observation in relation to dams explained a high proportion of longfin eel occurrence in NZFFD observations. Based on the findings of Crow and Dunn (2013), we included a predictor that described the presence of barriers downstream of the NZFFD observation (DSDam), a predictor describing the organisation that the NZFFD observer was representing (Org) and a predictor reflecting the fishing method used by the NZFFD observer (FishMeth). We did not include NZFFD observations with unknown organisation or unknown method identifiers (e.g., identified as "unk" in the NZFFD observation). We did not include NZFFD observations from organisations that contributed fewer than 30 NZFFD observations. Fishing method was important to include in the present study because the capture efficiency of methods differs between species and habitat (Joy, David et al. 2013). Org was included because some organisations focus on particular species during their sampling campaigns. For example, NZFFD observations from Fish and Game are likely to contain a high number of salmonid presences because they target areas where salmonids are present. We elected not to use observer as a predictor in the present analysis because there were more than 380 observer classes in the NZFFD dataset, which would create problems of model over-fitting. We also considered that using observer as a predictor would reflect similar information as the organisation predictor, which was already included.

Table 2-2:   Abbreviations, descriptions and units for environmental, spatial, hydrological and methodological predictor variables.

Dataset	Abbreviation	Description	Units
Environmental	Dist2Coast	Downstream distance to the ocean.	km
	DSDam	Presence (n=5,515) or absence (n=21,400) of downstream obstructions.	unitless
	StreamOrder	A number describing the Strahler order a reach in a network of reaches.	unitless
	Sinuosity	Actual distance divided by the straight line distance.	unitless
	headw_dist	Distance of the furthermost "source" or headwater reach from any reach.	m
	Segslpmax	Maximum segment slope along length of reach (°), square-root transformed (slope max+1).	Square-root of degrees
	Segslpmean	Mean segment slope along length of reach (°), square-root transformed (slope mean+1).	Square-root of degrees
	seg_rain	Mean annual segment rain.	mm
	us_rain	Mean annual upstream catchment average rain.	mm
	seg_ro_mm	Annual segment runoff.	mm
	seg_hard	Segment induration or hardness value.	Ordinal scale
	us_hard	Upstream catchment average induration or hardness value.	Ordinal scale
	seg_elev	Segment mean elevation above sea level of the watershed or basin.	m
	us_elev	Upstream catchment average mean elevation above sea level of the watershed or basin.	m
	seg_slope	Segment mean slope of the watershed or basin (°), square-root transformed (seg_slope+1).	Square-root of degrees
	us_slope	Upstream catchment average slope of the watershed or basin (°), square-root transformed (us_slope+1).	Square-root of degrees
	seg_tmin	Segment mean minimum winter air temperature	(°C x 10).
	us_tmin	Upstream catchment average mean minimum wintertime air temperature.	(°C x 10).
	seg_june	Segment June solar radiation.	(W/m²).
	us_june	Upstream catchment average June solar radiation.	(W/m²).
	seg_penpet	Segment penman potential evaporation measurement.	mm

Dataset	Abbreviation	Description	Units
	us_penpet	Upstream catchment average penman potential evaporation measurement.	mm
	seg_rnvar	Segment coefficient of variation of annual catchment rainfall.	mm
	us_rnvar	Upstream catchment average coefficient of variation of annual catchment rainfall.	mm
	seg_rd25	Segment rain days greater than 25mm/month.	mean # days/month
	us_rd25	Upstream catchment average rain days greater than 25mm/month.	mean # days/month
	seg_rd100	Catchment rain days greater than 100mm/month.	mean # days/month
	seg_phos	Segment catchment average of phosphorus.	Ordinal scale
	us_phos	Upstream catchment average catchment average of phosphorus.	Ordinal scale.
	seg_psize	Segment catchment average of particle size.	Ordinal scale.
	us_psize	Upstream catchment average of particle size.	Ordinal scale
	seg_pet	Segment annual potential evapotranspiration of catchment.	mm
	us_pet	Upstream annual potential evapotranspiration of upstream catchment.	mm
	seg_twar	Segment average within section mean January air temperature.	(°C x10).
	us_twarm	Upstream catchment average within section mean January air temperature.	(°C x10).
	DSDist2Lake	Downstream Distance to lake. Set to 500 km if no lake present downstream.	m
	DSmax_slope	Maximum downstream slope (°), square-root transformed (DSmax_slope +1).	Square-root of degrees
	DSav_slope	Average slope (°), square-root transformed (DSav_slope +1)	Square-root of degrees
	us_ind_forest	Upstream catchment average area with indigenous vegetation.	m^2
	US_RockPhos	Upstream catchment average phosphorous concentration of underlying rocks 1= very low to 5 = very high.	unitless
	USCalcium	Upstream catchment average calcium concentration of underlying rocks 1= very low to 5 = very high.	unitless

Dataset	Abbreviation	Description	Units
	us_LakeArea	Upstream catchment average area of the catchment covered by lakes.	m^2
	us_lakePerc	Upstream catchment average area of the catchment covered by lakes.	%
	Stream width	Wetted width of segment during mean annual low flow.	m
	Segshade	NZSegment area with riparian shade (proportion).	%
Spatial	X	Easting coordinates at the end of the NZSegment.	NZTM2000 Easting coordinate of downstream end of segment
	y	Northing coordinates at the end of the NZSegment.	NZTM2000 Northing coordinate of downstream end of segment
	xy	Multiple of xy from the cubic trend surface regression formula.	unitless
	y2	Square of y from the cubic trend surface regression formula.	unitless
	x3	Cube of x from the cubic trend surface regression formula.	unitless
	x2y	Multiple of x^2y from the cubic trend surface regression formula.	unitless
	xy2	Multiple of xy^2 from the cubic trend surface regression formula.	unitless
	y3	Cube of y from the cubic trend surface regression formula.	unitless
Hydrological	Constancy	Constancy of mean-monthly flows (see Colwell (1974)).	unitless
	Contingency	Consistency of mean-monthly flows among years (see Colwell (1974)).	unitless
	FRE1.Count	Number of flows greater than the median, after having standardised by mean flow	Counts/year
	FRE1.MaxDurBetween	Maximum duration between flows greater than the median, after having standardised by mean flow.	No. of days
	FRE1.MeanDurBetween	Mean duration between flows greater than the median, after having standardised by mean flow.	No. of days
	FRE10.Count	Number of flows greater than ten times the median, after having standardised by mean flow.	Counts/year

Dataset	Abbreviation	Description	Units
	FRE10.MaxDurBetween	Maximum duration between flows greater than ten times the median, after having standardised by mean flow.	No. of days
	FRE10.MeanDurBetween	Mean duration between flows greater than ten times the median, after having standardised by mean flow.	No. of days
	FRE5.Count	Number of flows greater than five times the median, after having standardised by mean flow.	Counts/year
	FRE5.MaxDurBetween	Maximum duration between flows greater than five times the median, after having standardised by mean flow.	No. of days
	FRE5.MeanDurBetween	Mean duration between flows greater than five times the median, after having standardised by mean flow.	No. of days
	JulianMax	Annual maximum flow, after having standardised by mean flow.	unitless
	JulianMin	Annual minimum flow, after having standardised by mean flow.	unitless
	l1	First linear moment of daily flows, after having standardised by catchment area.	$m^3s^{-1}km^{-2}$
	l2	Second linear moment of daily flows, after having standardised by catchment area.	$m^3s^{-1}km^{-2}$
	lca	Ratio of the first and second linear moment of daily flows, after having standardised by catchment area.	unitless
	lcv	Linear moment coefficient of variation, after having standardised by catchment area.	unitless
	lkur	Third linear moment of daily flows, after having standardised by catchment area.	$M^3s^{-1}km^{-2}$
	Mean1DayFlowMaxs	Mean annual maximum 1 day flow, after having standardised by mean flow.	unitless
	Mean1DayFlowMins	Mean annual minimum 1 day flow, after having standardised by mean flow.	unitless
	Mean7DayFlowMaxs	Mean annual maximum 7 day flow, after having standardised by mean flow.	unitless
	Mean7DayFlowMins	Mean annual minimum 7 day flow, after having standardised by mean flow.	unitless
	Mean90DayFlowMaxs	Mean annual maximum 90 day flow, after having standardised by mean flow.	unitless

Dataset	Abbreviation	Description	Units
	Mean90DayFlowMins	Mean annual minimum 90 day flow, after having standardised by mean flow.	unitless
	meanNeg	Mean number of all negative differences between days, after having standardised by mean flow.	Counts/year
	meanPos	Mean number of all positive differences between days, after having standardised by mean flow.	Counts/year
	MeanPulseLengthHigh	Mean duration of high pulses, after having standardised by mean flow.	unitless
	MeanPulseLengthLow	Mean duration of low pulses, after having standardised by mean flow.	unitless
	nNeg	Number of all negative differences between days, after having standardised by mean flow.	Counts/year
	nPos	Number of all positive differences between days, after having standardised by mean flow.	Counts/year
	nPulsesHigh	Number of high pulses within each water year, after having standardised by mean flow.	Counts/year
	nPulsesLow	Number of low pulses within each water year, after having standardised by mean flow.	Counts/year
	Predictability	Predictability of mean-monthly flows (Colwell 1974).	unitless
	Reversals	Number of hydrologic reversals, after having standardised by mean flow.	Counts/year
Methodological	FishMeth	Unique identifier of broad fishing method groupings: electric fishing (n=19,217) trapping (n=2,851), netting (n=2,259), visual (n=2,498), angling (n=90)	unitless
	Org	Unique identifier of 10 broad organisation groupings: DOC (n=10,467), NIWA (n=4,990), University (n=3,187), Council (n=3,162), Fish & Game (n=2,434), Consultant (n=2,131), Cawthron Institute (n=205), Boffa Miskall (n=137), Golder (n=133), Landcare (n=69)	unitless

2.3   Statistical Analysis

2.3.1   Developing Probability of Capture Models

Generalised Linear Models (GLM) (McCullagh and Nelder 1989) were used to derive probability of capture models for each species. Each GLM was developed using species presence/absence as the response variable and the predictors in Table 2-2. A stepwise regression procedure was used to fit a parsimonious binomial GLM describing fish occurrence. The stepwise fitting method began with a basic model where the only predictor was year, which was included in the GLM as a factor for which

each year of record was a class. Year was always included as step 1 in the GLM because the fitted coefficients for each year represented by this factor characterise temporal trends in predicted probability of capture (outlined in Section 2.3.2). The stepwise process then iteratively included predictors until there was insufficient improvement in the model. For all analyses, the improvement in the residual deviance, (i.e., new deviance – old deviance / saturated deviance – null deviance), which we refer to as R^2, was used as the criterion for including predictors. At each step, the predictor with the greatest improvement in R^2 was included, providing that its inclusion resulted in an improvement in R^2 of at least 0.5% (Vignaux 1994).

The receiver operating characteristic (ROC) was used to assess the model performance of each stepwise GLM. The performance of binary classification (e.g., presence/absence data) models such as those implemented in the present study are influenced by the probability threshold (Freeman and Moisen 2008), and this needs to be considered when assessing model performance. The probability threshold is the predicted occurrence value of binary data, above which the species being modelled is assessed to be present. We selected a classification threshold based on Cohen's Kappa (Cohen 1960), which maximises the agreement between two correct classification rates (i.e., correctly predicted presences and correctly predicted absences). The area under ROC curves (AUC) represents a measure of model performance that is independent of the probability threshold. The AUC reflects the ability of the model to correctly predict an outcome relative to random chance; an AUC value of 0.5 represents a model that is no better at correctly predicting outcomes than random chance, while a value of 1 indicates that presences and absences are perfectly discriminated. To assist with the interpretation of AUC values (i.e. how well the model predicts presence/absence) we used three broad scale classifications of model performance based on Cohen (1969) and Rice and Harris (2005). These authors considered that the minimum AUC values (to three decimal places) corresponding to small, medium and large effects could be 0.556, 0.639 and 0.714 respectively. When applying these thresholds to the present study, we considered these three AUC values represented low (0.556–0.638), medium (0.639–0.713) and high (>0.713) model performance. AUC values <0.556 were considered to represent models with a negligible improvement over what is correctly predicted by chance. We present two AUC values for each GLM: (1) one value from step 1 in the stepwise GLM fitting process where year is the only predictor; and (2) one value from the final stepwise GLM. The AUC value for step 1 provided an indication of the amount of variation explained by year alone, while the final stepwise AUC value provided a measure of the maximum model performance using all predictors.

The number of NZFFD observations repeatedly collected from an NZSegment was weakly related to the number of taxa found (R^2 = 0.126, P <0.001). This caused a potential bias between areas of the REC2 network where there have been differing numbers of NZFFD observations. To minimise this bias, fish data were sub-sampled by randomly selecting one NZFFD observation from each NZSegment before fitting the stepwise GLM outlined above in this section. We then repeated the random sub-selection procedure and refitted the stepwise GLM 20 times (bootstrapped models hereafter).

2.3.2   Characterising Temporal Trends in Predicted Probability of Capture

Estimates of the Change in Probability of Capture Attributable to Year

The stepwise GLMs described in Section 2.3.1 were used to evaluate the characteristic probability of capture and 95% confidence intervals (CI) for each year (i.e., for each class of the year factor included in the GLMs), while all other predictors included in the final stepwise GLM were held constant. All

continuous numerical predictors were assigned their mean value, and all categorical predictors were assigned the single class that occurred the most frequently. The predictor Org was set as Department of Conservation (DOC) because it represented c. 40% of the total observations in the NZFFD. The predictor FishMeth was assigned the class electric fishing because c. 70% of the observations were collected with this method. The DSDam predictor was set to 0, which represents areas not influenced by dams and corresponds to c. 80% of the NZFFD observations.

Probability of capture was then estimated with the fixed values listed above for each class of the fitted factor year (i.e., all 39 classes of the year predictor from 1977-2015). Fitted values generated with this approach represented a characteristic probability of capture for each year, with the variability between years being minimally influenced by other confounding variables. This process was repeated for each of the 20 bootstrapped models, for each species. The median characteristic probability of capture for each year and its 95% CI were then calculated over the 20 bootstrapped models for each species. These median values were taken as the final estimates of the characteristic probability of capture for each year and their associated 95% CI. We do not provide results from the 20 bootstrapped results in the main body of this report, but these are available for each species in Appendix A.

Sen Slope Analysis

The characteristic probability of capture for each year varied non-linearly across the time-series, and required simplifying for national reporting purposes. For each species, we fitted regression lines to the characteristic probability of capture values for each year and these slopes were interpreted as trends that represent the average annual rate of change in the probability of capture for each species. Regression lines were fitted with the non-parametric Sen Slope Estimator (SSE) (Sen 1968), because the response for each analysis was generally not normally distributed. The SSE is the median slope among all pairs of two-dimensional sample of points (i.e., the standardised indices and their respective years).

We classified the direction of the trend based on the method described in Larned, Snelder et al. (2015). This method considers the 95% CI for the fitted SSE and infers that the direction of the trend is known with confidence if that interval does not include zero[4]. If the confidence interval does contain zero it is concluded that either: (1) there are insufficient data, (2) data were too variable to confidently determine the trend direction or (3) that trends have reversed during the temporal period.

The SSE is generated using data points that are assumed to be free from imprecision. However, the true values of our characteristic predicted probability of capture values for each year were uncertain because they were derived from the GLM. To account for this uncertainty and to determine whether it affected the conclusions of our analysis, we modified the method described by Larned, Snelder et al., (2015). The modification involved using a weighted median value to calculate the SSE. The weighted SSE is abbreviated WSSE. Weighting points in regressions is commonly used to place higher emphasis on those observations for which there is greater confidence. A weighting value for all slopes connecting pairs of the characteristic probability of capture values and their respective years was defined as the inverse of the sum of the CI of both indices (i.e., the weight was higher for pairs of slopes that, collectively, had narrower CI). The weighted median (Cormen, Leiserson et al. 2009) was

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[4] An important technical detail arises here. In order to achieve a 95% confidence level procedure, the confidence intervals are at the 90% level, *not* 95%. The rationale is fully explained in Appendix 1 of Larned, Snelder et al. (2015). Briefly, this arises because the new direction-classifying procedure uses a two one-sided test ("TOST") methodology, rather than the traditional single "two-sided" method.

then estimated from all slopes and their respective weighting values. The CI for the weighted median slope was estimated using a bootstrap procedure in which the weighted median was estimated 1000 times from a random sample drawn with replacement from the original set of slopes and weightings.

In Section 3, we report trends based on both SSEs and WSSEs. Trends based on unweighted SSEs are consistent with the approach outlined by Larned, Snelder et al. (2015). The new WSSE approach was developed because it incorporates more of the information generated from the probability of capture models (i.e., CI associated with probability capture values). To our knowledge, the present study is the first to use WSSEs. Further analyses will be needed to quantify the comparative performance of SSEs and WSSEs; these analyses were beyond the scope of the current study.

To examine trends over different time periods, we calculated the SSE and WSSE using three time periods: 1977–2015, 1977–1994 and 1995–2015. The 1977–1994 and 1995–2015 time periods were requested by MfE to be consistent with other water quality trend analyses used for environmental reporting.

3 Results

3.1 Model Performance and Predictors

GLM results were generated for 13 species (Table 3-1). GLM results could not be calculated for the remaining 18 species there was no spatial information on the distributional boundaries for non-diadromous species or GLM's were overfitted. Explanations for model overfitting are outlined in the discussion. The following Results section only refers to the 13 species shown in Table 3-1.

The performance of GLM for each species was low when year was the only predictor (Table 3-1). The AUC values for these GLMs ranged from 0.539–0.596, suggesting that year explained small to negligible amounts of variation in species occurrences. Year alone explained a negligible amount of variation for shortfin eels (AUC ± 1 S.D: 0.539±0.005) and for kōaro (0.541±0.005). Year alone explained the most variation for longfin eels (0.596±0.005) and rainbow trout (0.596±0.008), but these AUC values still indicate that the year effect was small for these species.

The AUC values from the final stepwise GLMs ranged from 0.683–0.799 indicating that the performance of these models was moderate to high (Table 3-1). The lowest AUC (±S.D) for the final stepwise GLM was for common bully (0.683±0.006), and the highest was for redfin bully (0.799±0.005).

Table 3-1: **AUC values for stepwise GLM models using; (1) year as the only predictor, and (2) all variables selected from the stepwise GLM analysis.** Species are ordered alphabetically. Individual AUC values and variables used for each of the final stepwise GLM analyses are in Appendix B. Exotic fish refers to the presence of any non-native species. Native fish refers to the presence of any native species.

Species	AUC for year model	AUC year model S.D.	Performance of year model	AUC for final model	AUC final model S.D.	Performance of final model
Brown trout	0.575	0.004	low	0.732	0.004	high
Canterbury galaxias	0.589	0.010	low	0.732	0.010	high
Common bully	0.577	0.005	low	0.683	0.006	medium
Exotic fish[5]	0.568	0.004	low	0.713	0.004	medium
Kōaro	0.541	0.005	negligible	0.691	0.007	medium
Kōura	0.560	0.005	low	0.686	0.005	medium
Longfin eel	0.596	0.004	low	0.751	0.004	high
Native fish[5]	0.563	0.005	low	0.706	0.005	medium
Rainbow trout	0.596	0.008	low	0.742	0.008	high
Redfin bully	0.574	0.006	low	0.799	0.005	high
Shortfin eel	0.539	0.005	negligible	0.757	0.005	high
Torrentfish	0.561	0.006	low	0.732	0.007	high
Upland bully	0.560	0.006	low	0.700	0.006	medium

3.2 Trend Analysis Results

To aid comparisons of trends between species, time periods and statistical methods, we plotted the trend directions and magnitudes based on SSE and WSSE for each species of the 13 species on a single graph, with a separate graph for each time period (Figures 3.1-3.3). We express the trend slopes as annual rates of change in probability of capture as %/year. The 95 % CI for the Sen slopes are not shown on the plots, but Sen slopes are colour coded to indicate when they had a CI that included zero. Results for each species and time period are in Appendix C. Plots of the Sen slopes and characteristic rates of change in probability of capture attributable to year for each species are in Appendix D.

Throughout the results section, we use the term 'Sen slopes' to refer to both SSE and WSSE slopes. We refer to Sen slopes for which a positive direction was inferred with confidence as 'increasing trends', and Sen slopes for which a negative direction was inferred with confidence as 'decreasing trends'. We also use the term 'probability of capture' to mean characteristic probability of capture values for each year that were generated from the GLM fitted values; and refer to it either increasing (i.e., an 'increasing trend') or decreasing (i.e., an 'decreasing trend').

3.2.1 1977–2015 Time Period

Across the 13 species, trend directions were inferred with confidence (i.e., the CI of the slope did not include zero) for 19 of the 26 Sen slopes over the 1977–2015 time period. For each species, the estimated probability of capture increased or decreased by less than 0.5 %/year (Figure 3-1).

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[5] For clarification, "Native fish" refers to the presence of any native species identified in Table 2-1. Similarly, "Exotic fish" refers to the presence of any exotic species identified in Table 2-1.

There were a total of seven increasing trends and 12 decreasing trends. The median (± 95 % CI) magnitude of trends in probability of capture for the four species with increasing trends ranged from 0.04 (± 0.02)–0.36 (± 0.07) %/year. The median (± 95 % CI) magnitude of trends in probability of capture for the seven species with decreasing trends ranged from 0.05 (± 0.02)–0.44 (± 0.04) %/year.

All species with increasing trends were native, and all species with decreasing trends were exotic. Brown and rainbow trout had decreasing trends for both SSE and WSSE. Exotic fish also had decreasing trends for both SSE and WSSE. Common bully and Canterbury galaxias were the only native species with decreasing trends for both SSE and WSSE. For Kōaro and longfin eels, there was a decreasing trend for the WSSE, but the CI of the SSE crossed zero. Trend directions for SSE and WSSE were consistent (i.e., both were increasing or both were decreasing) for eight species. For the remaining five species, the 95% CI for either SSE or WSSE included zero.

Upland bully had the largest increasing trend, with median magnitudes (± 95 % CI) of 0.35 (± 0.04) and 0.36 (± 0.07) %/year (SSE and WSSE, respectively). Shortfin eel and native fish showed increasing trends for both SSE and WSSE. Brown trout had the largest decreasing trend, with median magnitudes (± 95 % CI) of 0.31 (± 0.04) and 0.44 (± 0.04) %/year (SSE and WSSE respectively).

Figure 3-1:   Median SSE and WSSE for the 1977–2015 time period. The vertical dashed-line indicates a Sen slope of zero. Sen slopes for which the confidence intervals included zero are indicated by red symbols (Uncertain). Species are ordered by unweighted slope magnitude.

3.2.2   1977–1994 Time Period

Across the 13 species, trend directions were inferred with confidence (i.e., the CI of the slope did not include zero) for 16 of the 26 Sen slopes over the 1977–1994 time period. Sen slopes were generally

higher than those observed over 1977–2015, with probability of capture values increasing or decreasing by up to 1.32 %/year (Figure 3-2).

There were a total of eight increasing trends and eight decreasing trends. The median (± 95 % CI) magnitude of trends in probability of capture for the four species with increasing trends ranged from 0.09 (± 0.03)–0.94 (± 0.10) %/year. The median (± 95 % CI) magnitude of trends in probability of capture for the seven species with decreasing trends ranged from 0.29 (± 0.03)–1.32 (± 0.19) %/year.

As with the 1977–2015 time period, all species with increasing trends were native, and all species with decreasing trends were exotic. Common bully and kōura were the only native species with decreasing trends for the WSSE and indeterminate trends (95 % CI included zero) for the SSE.

Trend directions for both SSE and WSSE were consistent for seven species. For the remaining six species, the 95% CI for either SSE or WSSE included zero. Upland bully had the largest increasing WSSE trend, with a median (± 95 % CI) magnitude of 0.94 (± 0.10) %/year. Longfin eel had the largest increasing SSE trend, with a median (± 95 % CI) magnitude of 0.64 (± 0.21) %/year. Native fish and torrentfish were the two other species that displayed increasing SSE and WSSE trends. Exotic fish had the largest decreasing trend, with median (± 95 % CI) magnitudes of 0.89 (± 0.25)–1.32 (± 0.19) %/year (SSE and WSSE respectively).
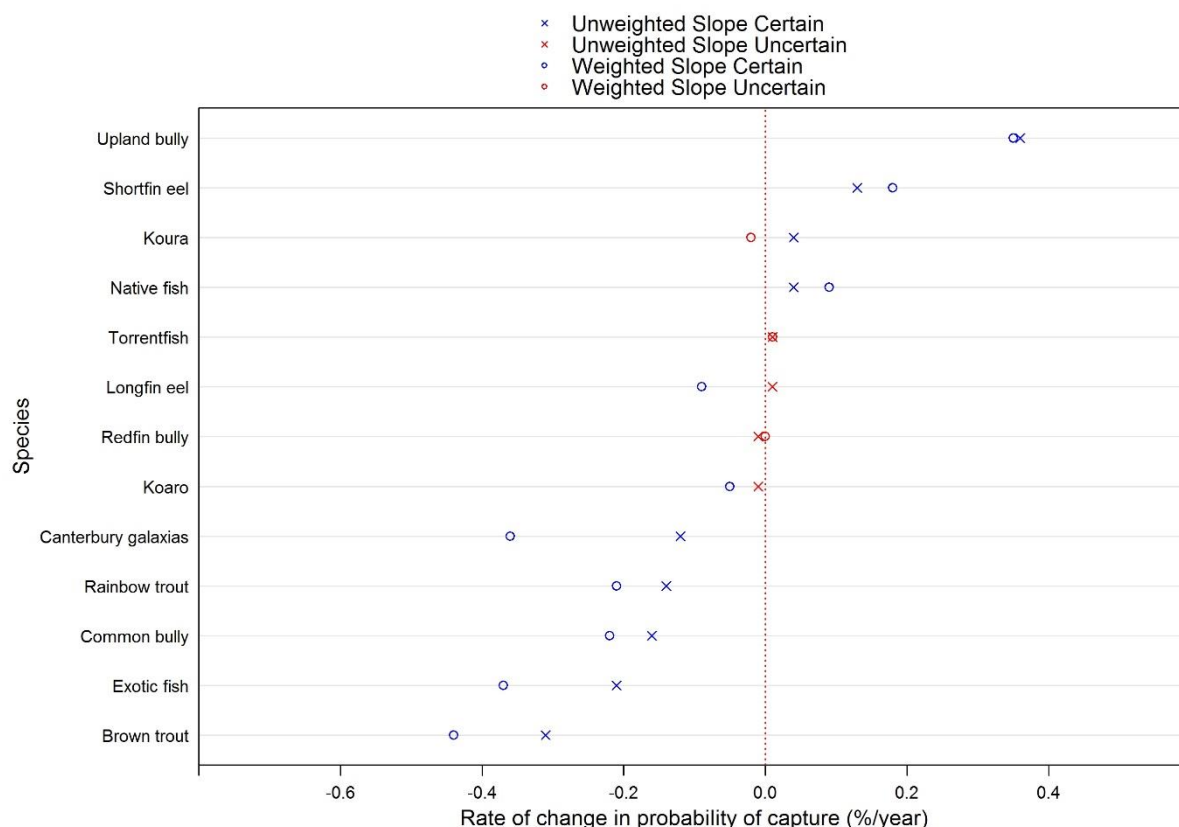

Figure 3-2:   **Median SSE and WSSE for the 1977–1994 time period.** The vertical dashed-line indicates a Sen slope of zero. Sen slopes for which the confidence intervals included zero are indicated by red symbols (Uncertain). Species are ordered by unweighted slope magnitude.

3.2.3 1995–2015 Time Period

Across the 13 species, trend directions were inferred with confidence (i.e., the CI of the slope did not include zero) for 13 of the 26 Sen slopes over the 1995–2015 time period (Figure 3-3). Sen slopes were similar to those in the 1977–2015 time period, with probability of capture values increasing or decreasing by up to 0.33 %/year with the exception of Canterbury galaxias (Figure 3-3). The median (± 95 % CI) decreasing trend magnitude for Canterbury galaxias was more than twice that of other species at 0.81(± 0.75) %/year (based on WSSE).

There were a total of five increasing trends and eight decreasing trends. The median (±95 % CI) magnitude of trends in probability of capture for the three species with increasing trends ranged from 0.13 (± 0.04)–0.33 (± 0.05) %/year. The median (±95 % CI) magnitude of trends in probability of capture for the six species with decreasing trends ranged from 0.02 (± 0.01)–0.81 (± 0.75) %/year.

In contrast to the other time periods, there was a positive trend in the 1995-2015 period for one exotic species, rainbow trout. Two native species also had increasing trends, and five native species had decreasing trends for at least one of the two slope estimates. Brown trout was the only exotic species with a decreasing trend.

Trend directions for both SSE and WSSE were consistent for four species. For the remaining nine species, the 95% CI for either the SSE or WSSE included zero. Shortfin eel had the largest increasing SSE and WSSE trends, with median (± 95% CI) magnitudes of 0.23 (± 0.03) and 0.33 (± 0.05) %/year, respectively. Rainbow trout also had increasing SSE and WSSE trends, with median (± 95 % CI) magnitudes of 0.10 (± 0.04) and 0.24 (± 0.07) %/year, respectively. Canterbury galaxias and brown trout both had decreasing SSE and WSSE trends. The median (± 95 % CI) decreasing SSE and WSSE trends for brown trout were 0.30 (± 0.09) and 0.31 (± 0.12) %/year, respectively. The median (± 95 % CI) decreasing SSE and WSSE trends for Canterbury galaxias were 0.73 (± 0.51) and 0.81 (± 0.75) %/year, respectively.
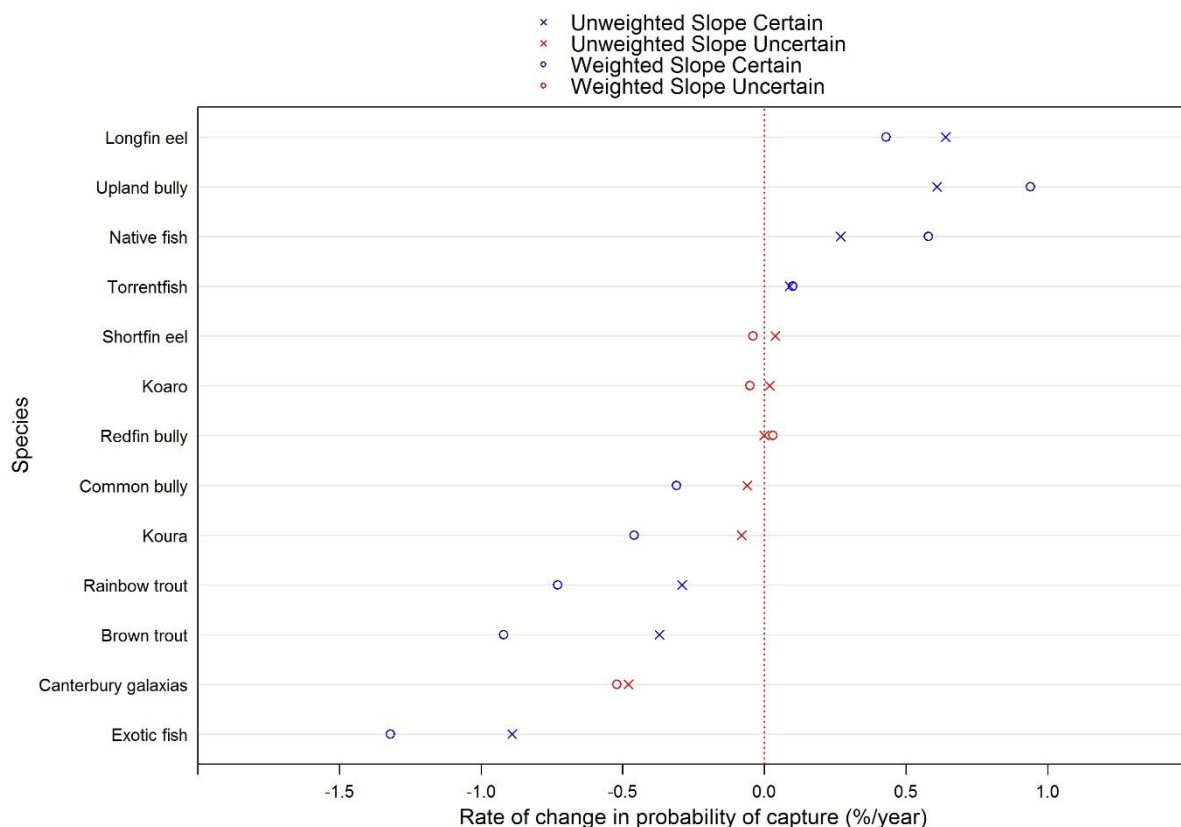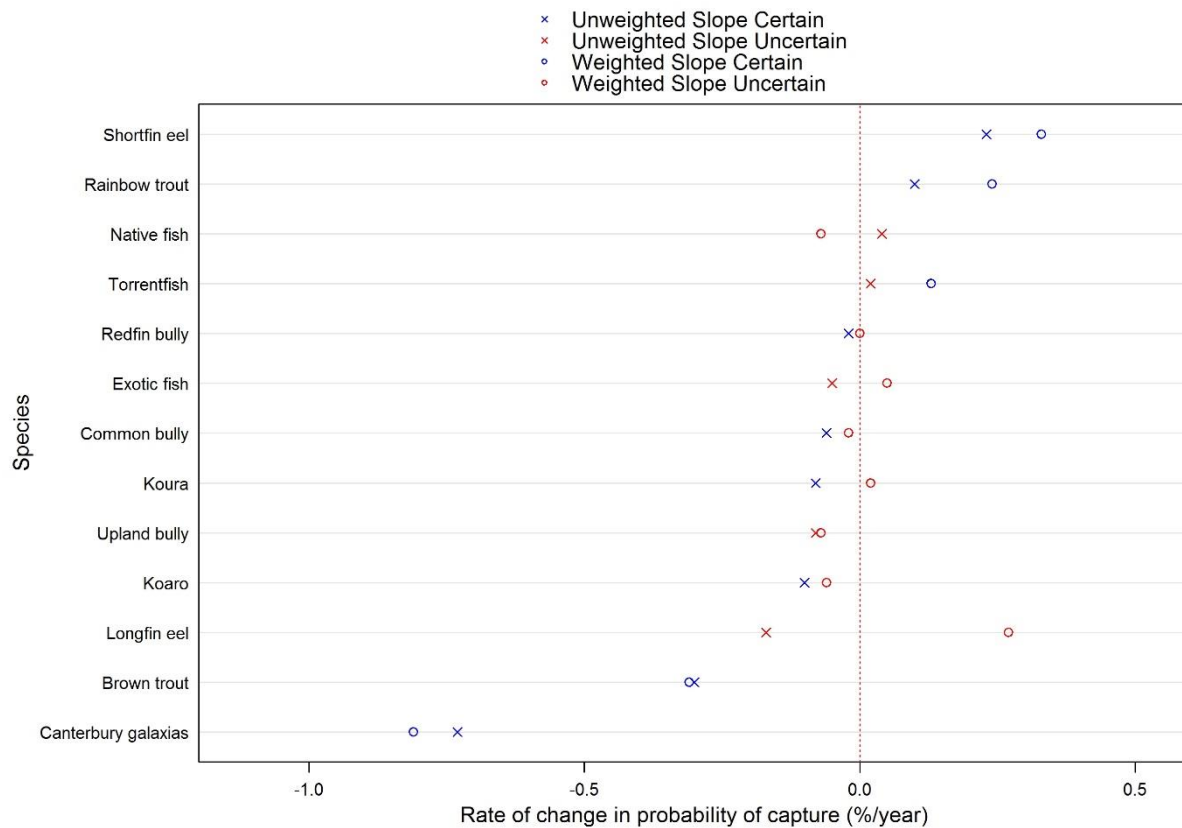
Figure 3-3:   Median SSE and WSSE slopes for the 1995-2015 time period. The vertical dashed-line indicates a Sen slope of zero. Sen slopes for which the confidence intervals included zero are indicated by red symbols (Uncertain). Species are ordered by unweighted slope magnitude.

3.3   Summary of Trend Directions

In this section, we summarise the number of increasing and decreasing trends observed over the 1977–2015 and 1995–2015 time periods only. We provide the summary for these two time periods because they include data from at least the last 20 years, which are likely to be the most informative for pending assessments by MfE of the current state of New Zealand's freshwater fishes. We present a single table that can be used to quickly identify species and trend directions.

A total of 46.2% (n=6) of the 13 species had at least one decreasing trend in both the 1977–2015 and 1995–2015 time periods (Table 3-2). Specifically, 42.3% and 30.8% of the Sen slopes (n=26) indicated decreasing trends for the 1977–2015 and 1995–2015 time periods, respectively. Brown trout and Canterbury galaxias had decreasing SSE and WSSE trends over both time periods. Common bully had decreasing SSE and WSSE trends for 1977–2015, but only the SSE was decreasing for 1995–2015. All remaining species showed declining trends for one or neither of the time periods.

Across the 1977–2015 and 1995–2015 time periods, 30.8% (n=4) and 23.1% (n=3) of the 13 species showed at least one increasing trend. Specifically, 26.9% and 19.2% of the Sen slopes (n=26) inferred increasing trends for the 1977–2015 and 1995–2015 time periods respectively. Shortfin eels showed increasing trends for all time periods using SSE and WSSE. All remaining species showed declining trends for one or neither of the time periods.

Table 3-2:   Number of increasing and decreasing trends for the 1977–2015 and 1995–2015 time periods.
Counts refer to SSE and WSSE trends within each time period for each species (maximum of two possible trend results for each species). Total % was calculated relative to the number of Sen slopes calculated for the time period (n=26). Species are ordered alphabetically.

Species	Decreasing trends		Increasing trends	
	1977–2015	1995–2015	1977–2015	1995–2015
Brown trout	2	2		
Canterbury galaxias	2	2		
Common bully	2	1		
Exotic fish	2			
Kōaro		1		
Kōura		1	1	
Longfin eel	1			
Native fish			2	
Rainbow trout	2			2
Redfin bully		1		
Shortfin eel			2	2
Torrentfish				1
Upland bully			2	
Total number	11	8	7	5
Total %	42.3	30.8	26.9	19.2

4   Discussion

4.1   Overview of Trends in the New Zealand freshwater Fish Community

The freshwater fish community composition recorded on NZFFD observations showed continuous change over 1977–2015. Across three time periods, there was at least one confident trend in probability of capture for each of the 13 species analysed. A total of 78 Sen slopes (both SSE and WSSE) were calculated for the 13 species for each of three time periods. From the 78 Sen slopes, 35 % (n=27) corresponded to decreasing trends, 28% corresponded to increasing trends, and the remainder were indeterminate. The average (±95 % CI) magnitude of the decreasing trends was 0.38 (± 0.12) %/year. The average (±95 % CI) magnitude of the increasing trends was 0.27 (± 0.05) %/year.

4.2   Interpreting SSE and WSSE trends

We recommend using both SSE and WSSE results when interpreting trends for New Zealand freshwater fishes. Trends based on unweighted SSEs are consistent with the approach outlined by Larned, Snelder et al. (2015). We developed the WSSE approach to incorporate uncertainty associated with the probability of capture estimates for each year. Trend directions and magnitudes inferred from SSE and WSSE were generally consistent for each species, but did differ occasionally. Across all 78 Sen slopes, the trend magnitude from WSSE was predominantly larger than the trend magnitude from the SSE, but this was not true for seven cases (for koura over the 1997–2015 time period, longfin eel over the 1977–1994 time period, and for 5 of the 13 species over the 1995–2015 time period). The two methods also varied between species and time periods in the degree to which trends could be inferred with confidence. The variability in the trend directions and magnitudes between SSE and WSSE make it important to examine both results when identifying trends for freshwater fishes. Until further testing is completed on the WSSE, we are unable to determine if it is a better descriptor of trends than the SSE.

4.3   Final stepwise model performance and temporal confounding in the NZFFD.

Temporal variability in sampling methodology and sampling locations should be considered when interpreting temporal trends in the NZFFD. This temporal confounding makes it difficult to determine whether trends in NZFFD data are solely associated with changes in abundance, with changes in habitat quality or sampling efficiency, or a mixture. In the present study, we used GLMs to reduce the influence of confounding variables on temporal trends, and this approach or a similar one should always be used before analysing trends in NZFFD data.

Assessments of GLM performance indicated that the year predictor only explained small amounts of variation relative to environmental conditions and sampling variability in the NZFFD. AUC values from models using year only (i.e., Step 1 of the final stepwise GLM) explained small to negligible amounts of variation in species occurrences, but final stepwise models explained moderate to large amounts of variation. The increased performance of final stepwise models were generated by the addition of up to 10 predictors relating to sampling methodology and environmental conditions. Predictors for fishing method and/or organisation were included in every final GLM (Appendix B), suggesting that aspects of sampling methodology explain the largest amounts of species occurrences in the NZFFD. Remaining predictors used across all final stepwise GLM's related to environmental and hydrological conditions (e.g., temperature, slope, elevation, distance from the sea, flow variability).

4.4 Consistent species trends from the 1977–2015 and 1995–2015 time periods

For brown trout, the decreasing probability of capture over 1977–2015 corresponds to a decline of 11.8% and 16.7% over the 39-year period, for SSE and WSSE respectively. This result was unexpected because for the last 25 years there has been extensive documentation of the impacts of brown trout on native species in New Zealand rivers (Townsend, C. R. and Crowl 1991; McDowall 2006; McIntosh, McHugh et al. 2010). The decreasing trend observed in this report suggests that either rates of brown trout removal from existing habitats exceed rates of expansion into new habitats, or that range contraction is occurring. The first explanation is more likely because brown trout are known to have invaded new habitats in recent years (DOC, unpubl. data). Decreasing trends for brown trout are supported by the recorded loss of brown trout from several New Zealand waterways, with gradual habitat degradation considered to be a primary contributing factor [e.g., Horokiwi Stream (Jellyman, D J, Glova et al. 2000)]. Compared to native fish species in general, trout may be more sensitive to the pressures associated with land-use change and hydrological alteration (Leprieur, Hickey et al. 2006) so may be disproportionately affected by such activities.

Decreasing trends in Canterbury galaxias probability of capture in the 1995–2015 and 1977-2015 time periods are consistent with the outcomes of the latest threat rankings for New Zealand freshwater fishes (Goodman, Dunn et al. 2014). Goodman, Dunn et al. (2014) placed Canterbury galaxias into the classification of 'At Risk-declining' for the first time, on the basis that this species occupies an area smaller than 10 km^2 and has a predicted decline of 10–30 %. The time period used in the threat classification system is 10 years or three generations, whichever is longer (Townsend, A. J., de Lange et al. 2008). These threat classification criteria suggest that the Canterbury galaxias population experienced a decline of at least 10% over the previous 10 year time period (2003–2013). The present study showed that the probability of capture for Canterbury galaxias is decreasing by 0.73–0.81 %/year (SSE and WSSE respectively, with CIs 0.51 and 0.75), which corresponds to a decrease over 10 years of 7.3 (± 5.1)– 8.1(± 7.5) % for SSE and WSSE respectively. These rates of decrease are slightly lower than the 10 % minimum value suggested by Goodman, Dunn et al (2014), but the CI of both estimates include the 10 % per decade threshold.

Shortfin eel was the only species to show increasing trends for all Sen slopes for the 1977–2015 and 1995–2015 periods. Shortfin eel are considered to have a large and stable population and a conservation status of 'Not Threatened' (Goodman, Dunn et al. 2014). Increasing trends for shortfins were also discussed in a recent review of the information available for monitoring trends and assessing the status of New Zealand freshwater eels (Haro, Dekker et al. 2015). The authors concluded that catch per unit effort (CPUE) declined in the 1990s, then increased in the mid-2000s. The stability of the shortfin eel population in New Zealand may also be attributable to stable recruitment rates over the last 17 years (Martin, Boubée et al. 2013).

4.5 Limitations of the present study and future improvements

Trend direction could not be inferred for 18 of the species in Table 2-1 because there was no spatial information on the distributional boundaries for non-diadromous species or GLM's were overfitted. Data on spatial extent of non-diadromous species distributions was required to ensure that the predictive models only used information from within species ranges. Spatial information on the distributional boundaries for the non-diadromous species could be calculated in the future by using GIS to identify the catchment boundaries of the REC2 network where their presences were observed in NZFFD observations. Distributional boundaries for non-diadromous species were not calculated

because it was beyond the scope of the present study. Distributional boundaries will be required for assessments of state and trends in critically endangered non-diadromous galaxiid populations (Goodman, Dunn et al. 2014). The original distributions of these species have been impacted by exotic fishes (McDowall 2006), making their existing population status important to consider.

For some species, insufficient spatial replication resulted from randomly selecting one NZFFD observation from each NZSegment. This step severely reduced the data available for modelling, particularly for non-diadromous species and for some diadromous species with distributions limited to coastal areas, such as īnanga (McDowall 2010). Low levels of spatial replication caused perfect separation (i.e., model overfitting) in the binary response (i.e. presences and absences are perfectly separated). Perfect separation occurs when one predictor perfectly separates the response, which can generate unreliable parameter estimates in the model (Heinze and Schemper 2002). This was a concern for the present study given we utilised the parameter estimates for the year predictor. One solution to this problem is to repeat the present approach with an analysis that is designed to minimise the effect of perfect separation (see Heinze and Schemper 2002) or analyses that are less susceptible to model over fitting such as Boosted Regression Trees (BRT) (Elith, Leathwick et al. 2008). These alternative analyses were not explored because they were beyond the scope of the study.

The trends reported in the present study are not representative of all freshwater habitats in New Zealand, because of the limitations associated with the sampling methods used to collect the NZFFD observations. Freshwater fishes occupy a diverse range of habitats, from deep lowland lentic water bodies (such as lakes, wetlands and estuaries) to shallow fast flowing streams in the high country (McDowall 1990). Moreover, some fish species can occupy a broad range of habitats during different life history stages (McDowall 1990; Jellyman, D. J., Bonnett et al. 2003; Jowett and Richardson 2008; McDowall 2010). Most NZFFD observations were generated using electric fishing, which is most effective in wadeable stream habitat (Joy, David et al. 2013). The high number of electric fishing observations may over-represent the species and/or life stages occupying wadeable stream habitats compared to the species and/or life stages from non-wadeable habitats. Thus, the analyses in this report predominantly represents trends for fishes found in wadeable streams.

Multicollinearity between predictors is a well-known statistical problem in (McCullagh and Nelder 1989; Legendre 1990; Zar 1999), which may have influenced the temporal trends presented in the present study. Multicollinearity can affect the ability of the GLM to correctly estimate model parameters (Legendre 1990; Legendre and Legendre 1998), because the model coefficients are calculated relative to the other predictors (Zar 1999). The coefficients estimated for the year predictor could therefore differ between final stepwise GLMs that have different combinations of predictor variables if multicollinearity exists. The stepwise procedure used in the present study minimised high levels of collinearity between predictors by selecting orthogonal (uncorrelated) predictors (Legendre and Legendre 1998). There are several additional approaches that could be used in future studies to identify the unique and shared variance contributions of predictors (Borcard, Legendre et al. 1992; Graham 2003; Peres-Neto, Legendre et al. 2006). Identifying unique and shared contributions for predictors was beyond the scope of the present study.

The present study describes trends in the relative abundance of fish species based on NZFFD observations, but it does not assess the ecological or management implications of the trends. Ecological and management implications would need to be assessed separately for each species, because fishes experience different population pressures and support different socioecological values (McDowall 1990; McIntosh, Townsend et al. 1992; Townsend, C R. 1996; McDowall 2010;

McDowall 2011). Assessments of the implications of trends in freshwater fish species are likely to be needed soon, given the large and increasing proportion of native fish species classified as 'Threatened' or 'At Risk' (Allibone, David et al. 2010; Goodman, Dunn et al. 2014).

4.6 Summary of future improvements and recommendations about improving the spatial and environmental representativeness of the NZFFD

As requested by MfE, the following section is a bullet point list that summarises the limitations of the present study and future improvements outlined throughout the Discussion.

- Compare slopes inferred by WSSE and SSE for different simulated datasets.

- Identify distributional boundaries for the non-diadromous fishes that currently do not have these data available within the REC2. This would allow trends to be examined for some non-diadromous species that could not be included in the present study.

- Repeating the present approach with a GLM analysis designed to minimise the effect of perfect separation (see Heinze and Schemper 2002) or using an analysis such as Boosted Regression Trees (BRT), may allow trends to be calculated for species with limited spatial distributions that caused perfect separation in the present study.

- Utilising different classes of the Fishmeth predictor "netting" to generate predicted capture values may produce trends that are more representative of deeper habitats (Elith, Leathwick et al. 2008).

- Exploring the unique and shared variance contributions of predictors (Borcard, Legendre et al. 1992; Graham 2003; Peres-Neto, Legendre et al. 2006) would help identify the level of multicollinearity in final GLMs.

- Assessing the ecological or management implications of the trends outlined in the present study should be assessed separately for each species, because fishes experience different population pressures and support different socioecological values

5   Acknowledgements

6   Glossary of Abbreviations and Terms

AUC   Area under ROC curves

CI   95 % confidence interval

DOC   Department of Conservation

GIS   Geographic Information System

GLM   Generalised Linear Models

MfE   Ministry for the Environment

MPI   Ministry for Primary Industry

NZFFD   New Zealand Freshwater Fish Database

NZTM   New Zealand Transverse Mercator

ROC   Receiver Operating Characteristic

REC   River Environment Classification

S.D   Standard Deviation

SSE   Unweighted Sen slope

WSSE   Weighted Sen slope

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Appendix A   Bootstrapped Results

Characteristic predicted probability of capture attributable to year (black lines) and 95% confidence interval (red lines) for each species; for each of the 20 Bootstrapped Datasets. Individual model results are shown as dashed lines while the median characteristic predicted probability of capture attributable to year and median 95% confidence interval are shown as solid lines. Species plots are listed alphabetically.

Common bully

Exotic

Koaro

Koura

Temporal Trends in the Relative Abundance of New Zealand Freshwater Fishes

Longfin eels

Native

Rainbow trout

Redfin bully

Shortfin eels

Torrent fish

Upland bully

Temporal Trends in the Relative Abundance of New Zealand Freshwater Fishes
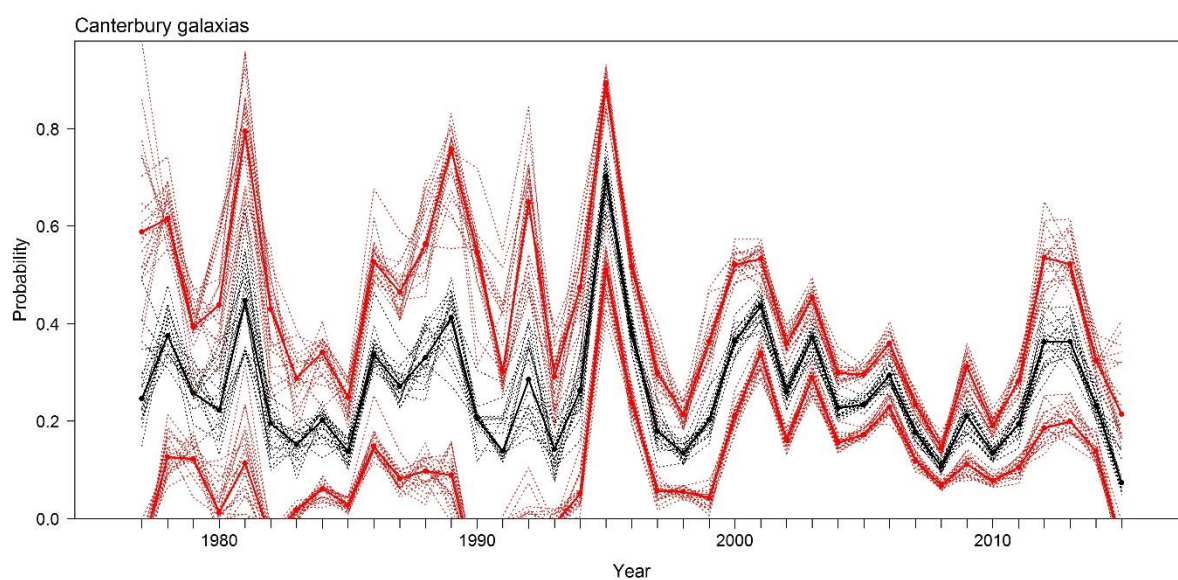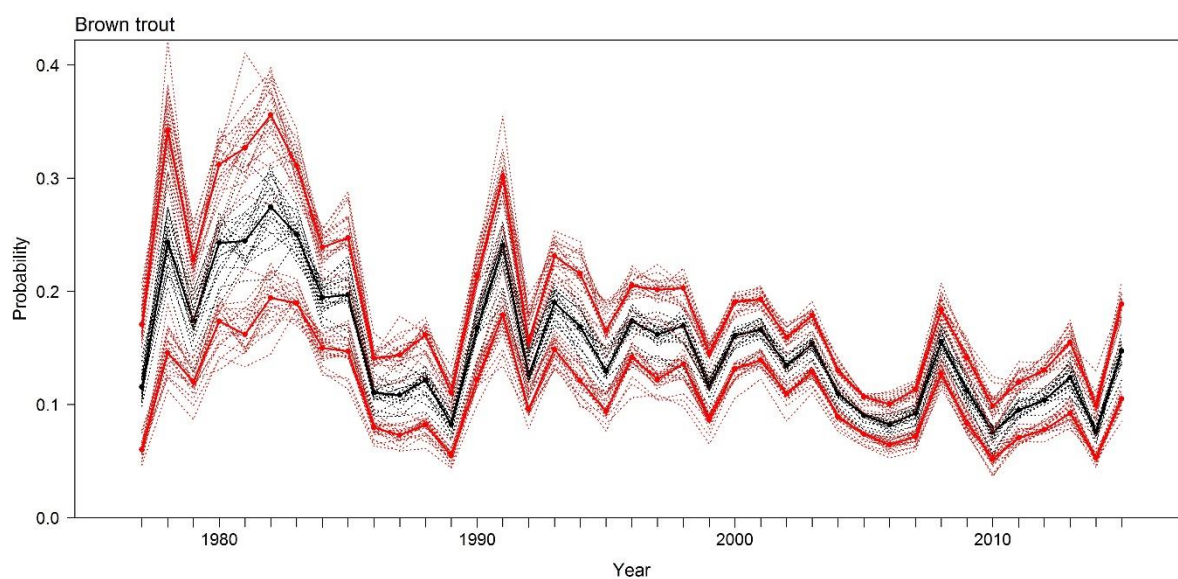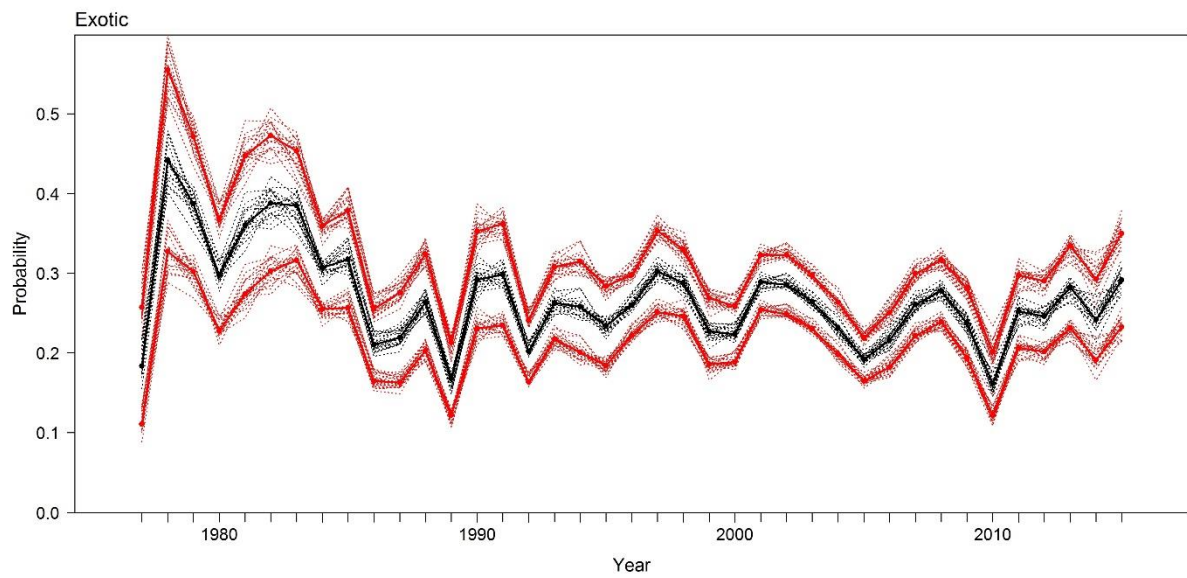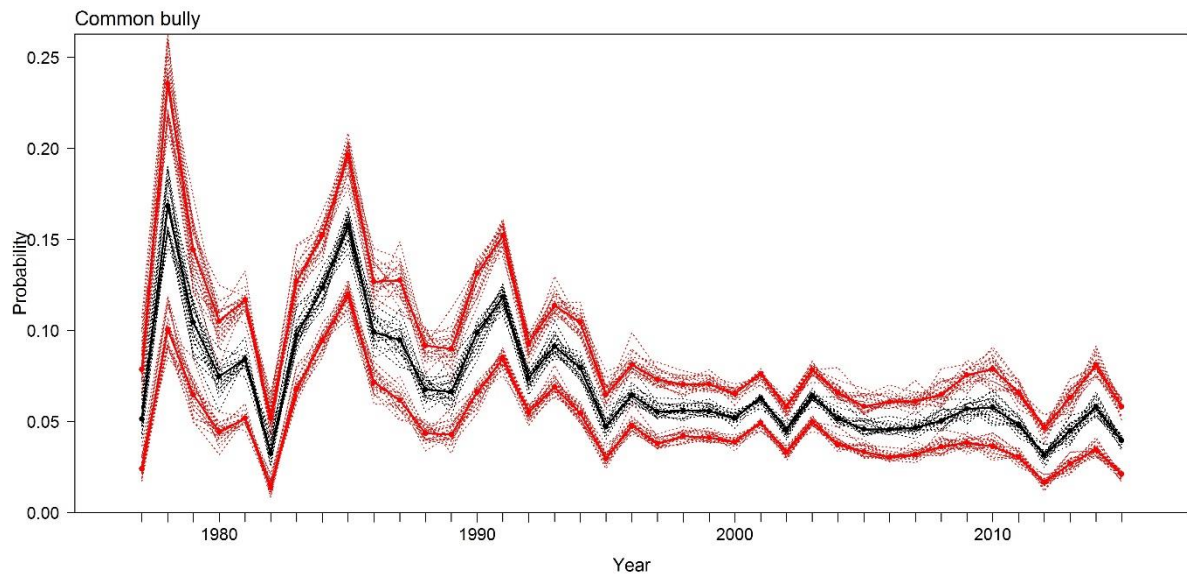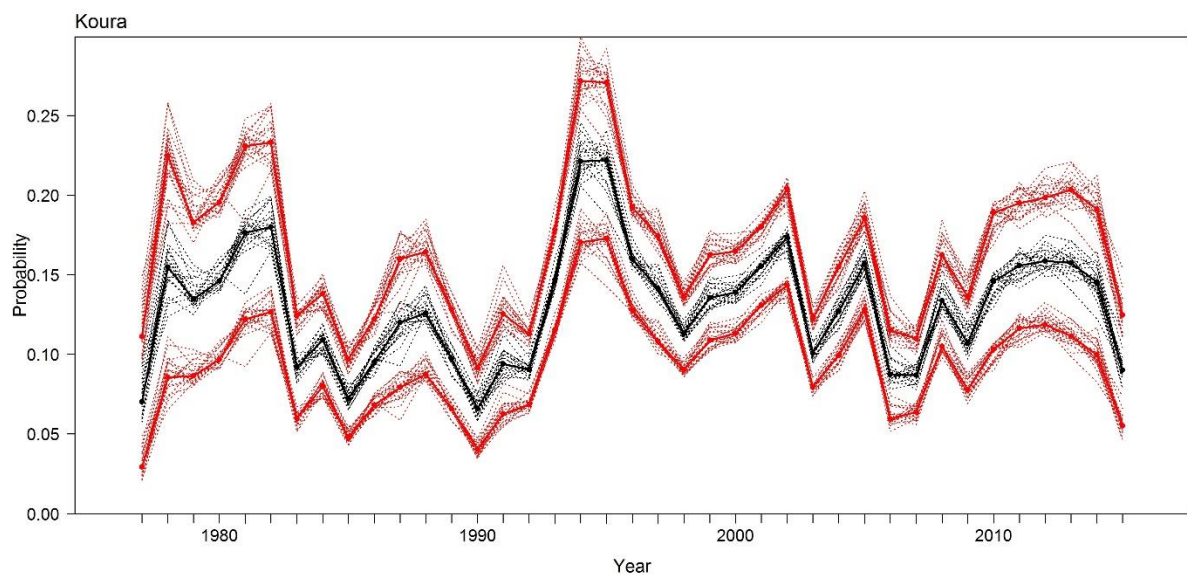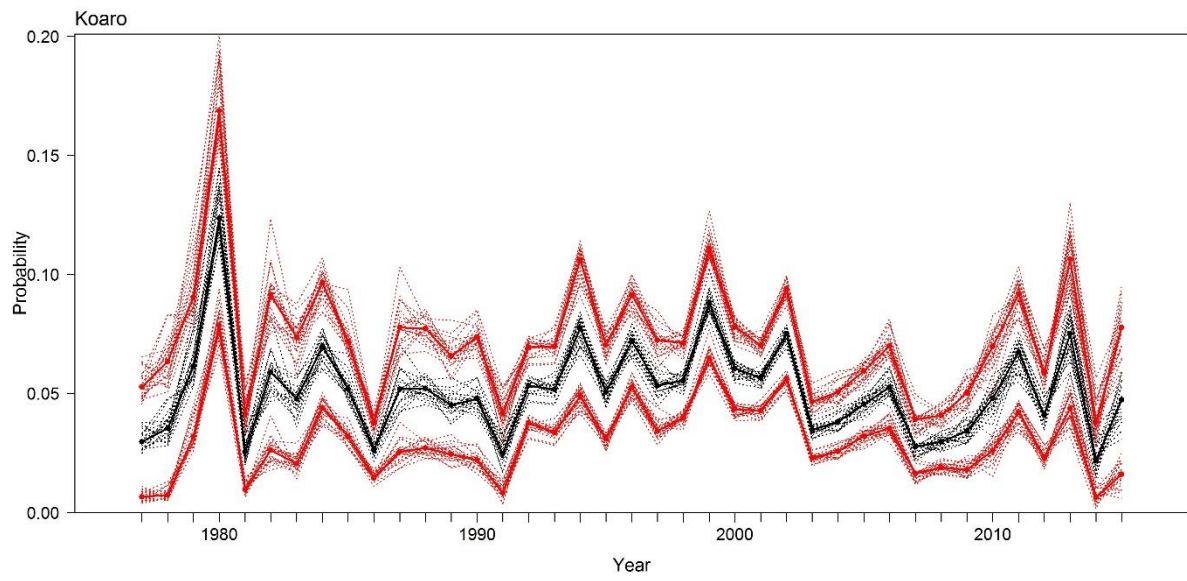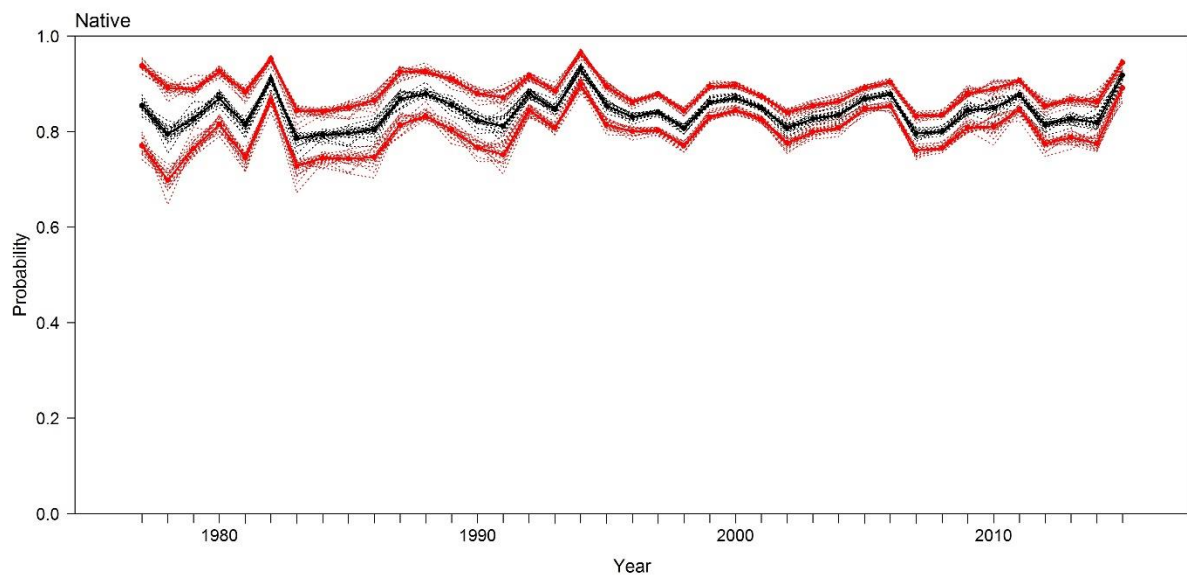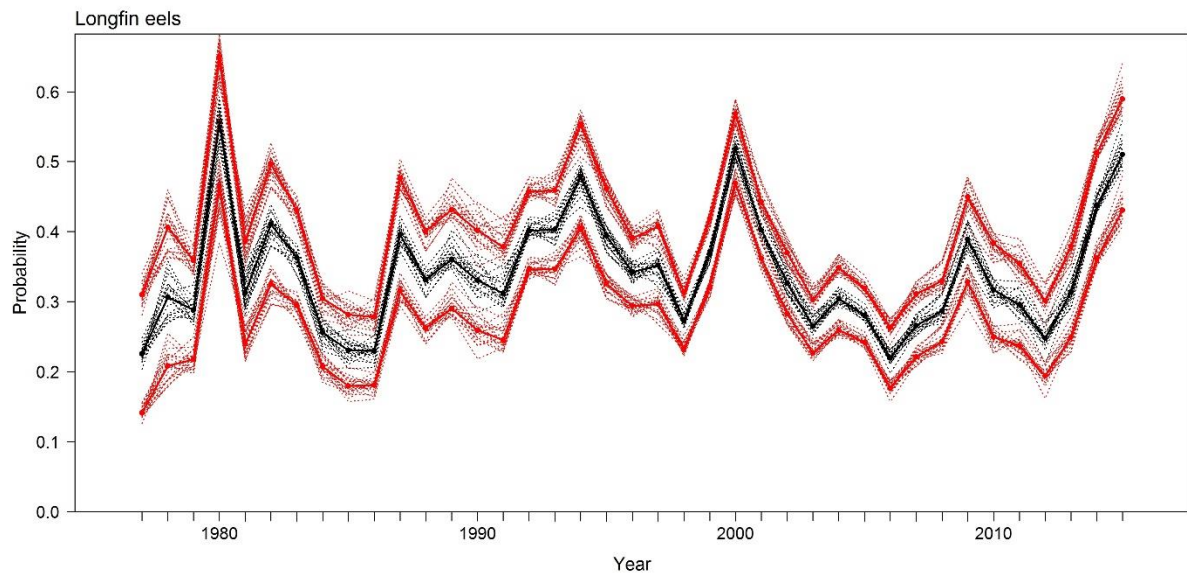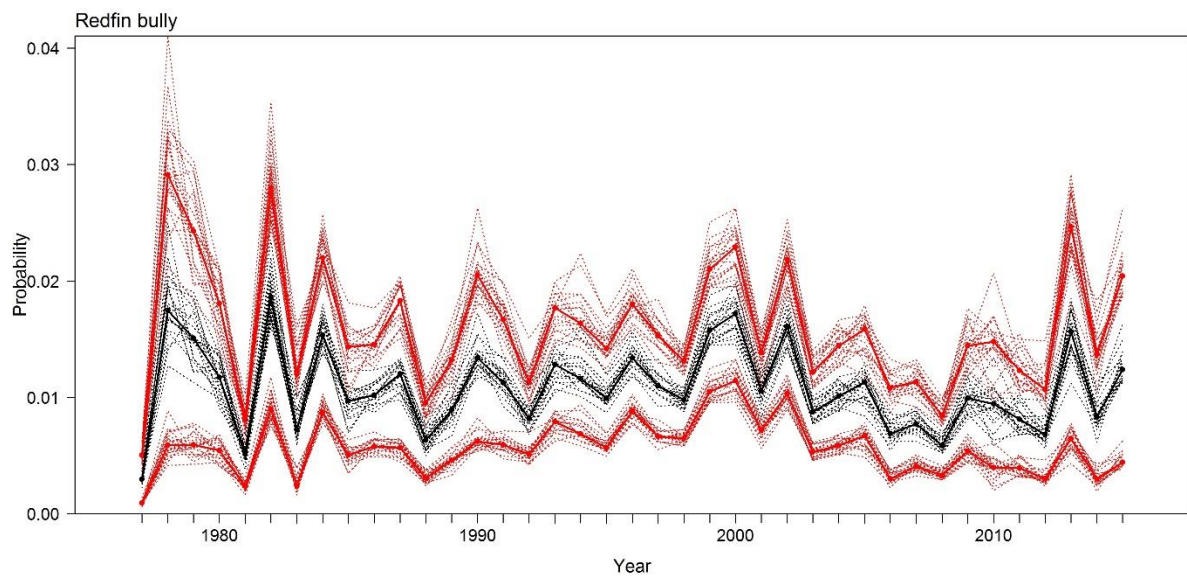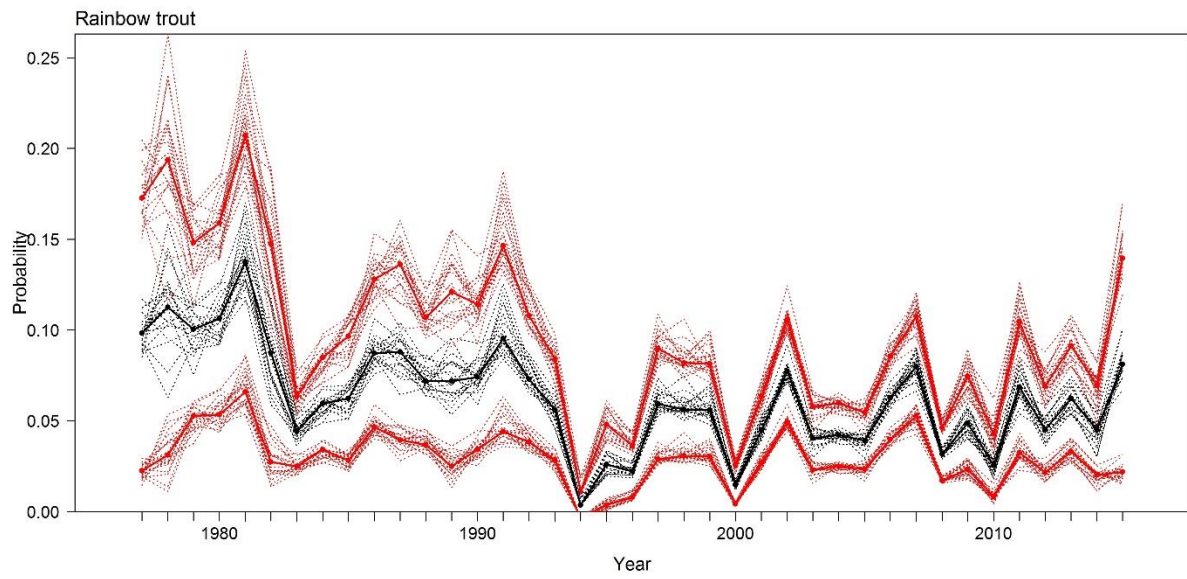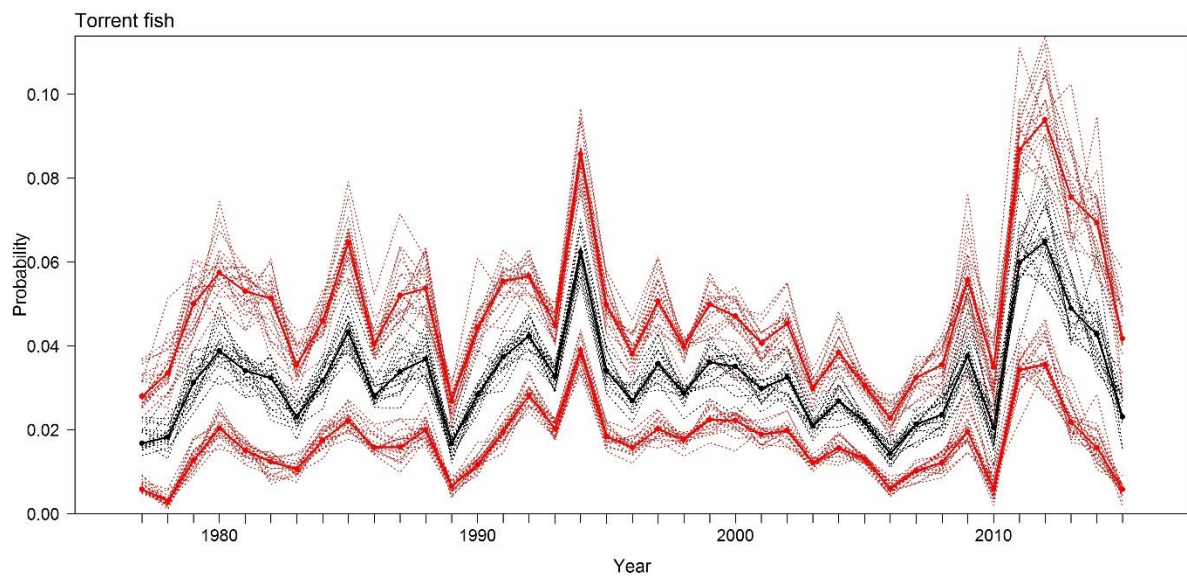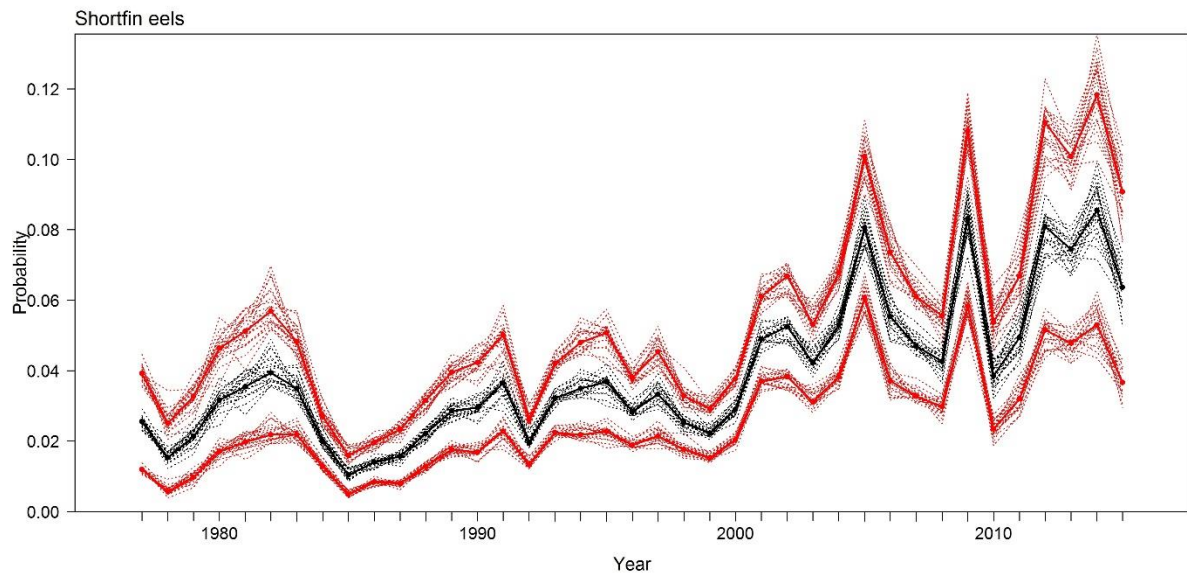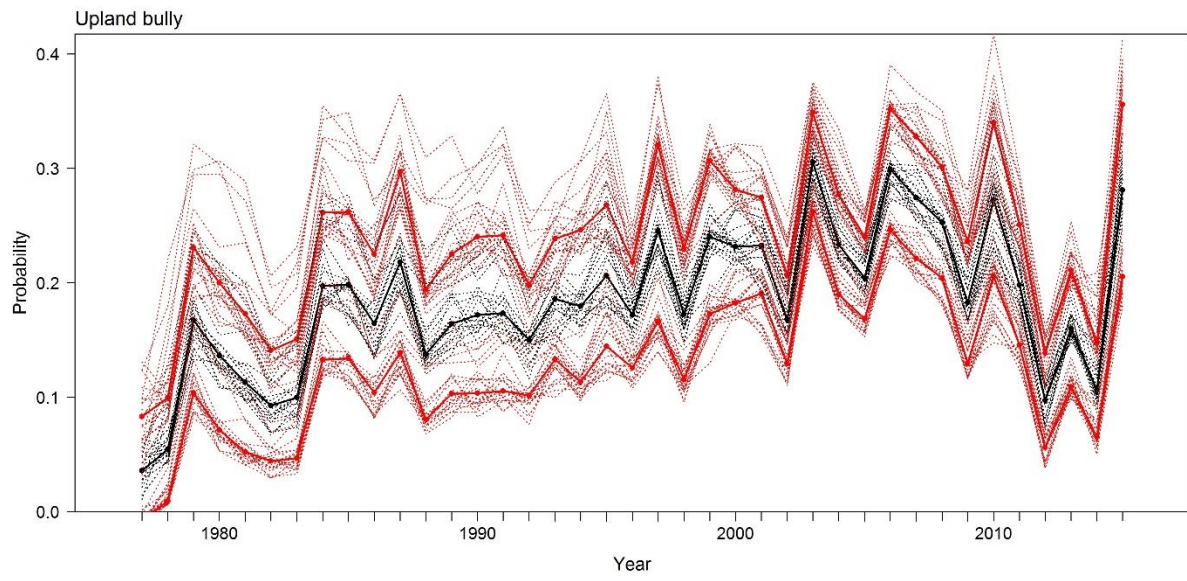
Appendix B   The AUC Results

The AUC results for each of the 20 bootstrapped datasets: AUC results are shown for GLM step 1 where year was the only predictor and the final stepwise GLM. Predictors selected from the stepwise GLM analysis are shown in order of addition with the exception of year which was always added during the first step.

Species	Bootstrap	AUC	AUC S.D	Predictor code (see Table 2-2 for descriptions)
Brown trout	1	0.574	0.004	year
Brown trout	1	0.725	0.004	year + us_tmin + org + fishmeth + StreamOrder + DSav_slope + xy2 + nNeg
Brown trout	2	0.577	0.004	year
Brown trout	2	0.73	0.004	year + us_tmin + org + fishmeth + StreamOrder + DSav_slope + NPulsesHigh+ y3 + nNeg
Brown trout	3	0.578	0.004	year
Brown trout	3	0.737	0.004	year + us_tmin + org + fishmeth + StreamOrder + DSav_slope + NPulsesHigh+ y3 + nNeg
Brown trout	4	0.574	0.004	year
Brown trout	4	0.728	0.004	year + us_tmin + org + fishmeth + DSav_slope + MeanPulseLengthLow+ y3 + StreamOrder
Brown trout	5	0.573	0.004	year
Brown trout	5	0.734	0.004	year + us_tmin + org + fishmeth + StreamOrder + DSav_slope + NPulsesHigh+ y3 + nNeg
Brown trout	6	0.576	0.004	year
Brown trout	6	0.737	0.004	year + us_tmin + org + fishmeth + StreamOrder + DSav_slope + xy2 + NPulsesHigh+ xy
Brown trout	7	0.577	0.004	year
Brown trout	7	0.738	0.004	year + org + fishmeth + StreamOrder + DSav_slope + xy2 + nNeg + Mean90DayFlowMax+ xy
Brown trout	8	0.575	0.004	year
Brown trout	8	0.711	0.004	year + us_tmin + org + fishmeth + StreamOrder + DSav_slope + xy2 + nNeg
Brown trout	9	0.579	0.004	year
Brown trout	9	0.724	0.004	year + us_tmin + org + fishmeth + StreamOrder + DSav_slope + xy2 + nNeg
Brown trout	10	0.576	0.004	year
Brown trout	10	0.755	0.004	year + org + fishmeth + StreamOrder + DSav_slope + xy2 + nNeg + Mean90DayFlowMax+ xy
Brown trout	11	0.575	0.004	year
Brown trout	11	0.73	0.004	year + us_tmin + org + fishmeth + DSav_slope + MeanPulseLengthLow+ y3 + StreamOrder
Brown trout	12	0.575	0.004	year
Brown trout	12	0.727	0.004	year + us_tmin + org + fishmeth + StreamOrder + DSav_slope + xy2 + nNeg
Brown trout	13	0.573	0.004	year
Brown trout	13	0.735	0.004	year + us_tmin + org + fishmeth + StreamOrder + DSav_slope + xy2 + nNeg
Brown trout	14	0.574	0.004	year
Brown trout	14	0.744	0.004	year + org + fishmeth + StreamOrder + DSav_slope + xy2 + nNeg + Mean90DayFlowMax+ xy + nPos

Species	Bootstrap	AUC	AUC S.D	Predictor code (see Table 2-2 for descriptions)
Brown trout	15	0.575	0.004	year
Brown trout	15	0.734	0.004	year + us_tmin + org + fishmeth + StreamOrder + DSav_slope + xy2 + FRE1.MaxDurBetween + xy
Brown trout	16	0.575	0.004	year
Brown trout	16	0.726	0.004	year + us_tmin + org + fishmeth + StreamOrder + DSav_slope + xy2 + nNeg
Brown trout	17	0.577	0.004	year
Brown trout	17	0.728	0.004	year + us_tmin + org + fishmeth + StreamOrder + DSav_slope + xy2 + nNeg
Brown trout	18	0.575	0.004	year
Brown trout	18	0.726	0.004	year + us_tmin + org + fishmeth + StreamOrder + xy2 + DSav_slope + nNeg
Brown trout	19	0.574	0.004	year
Brown trout	19	0.74	0.004	year + us_tmin + org + fishmeth + StreamOrder + DSav_slope + NPulsesHigh+ y3 + nNeg
Brown trout	20	0.571	0.004	year
Brown trout	20	0.731	0.004	year + us_tmin + org + fishmeth + StreamOrder + DSav_slope + NPulsesHigh+ y3
Canterbury galaxias	1	0.588	0.01	year
Canterbury galaxias	1	0.728	0.01	year + nNeg + fishmeth + us_tmin + Dist2Coast + headw_dist + lca + Mean7DayFlowMins + seg_penpet
Canterbury galaxias	2	0.588	0.01	year
Canterbury galaxias	2	0.741	0.01	year + nNeg + fishmeth + us_tmin + Dist2Coast + lkur. + headw_dist + Mean7DayFlowMaxs + seg_penpet + seg_hard
Canterbury galaxias	3	0.59	0.011	year
Canterbury galaxias	3	0.726	0.01	year + nNeg + fishmeth + us_tmin + Dist2Coast + headw_dist + lkur + Mean90DayFlowMaxs
Canterbury galaxias	4	0.599	0.01	year
Canterbury galaxias	4	0.734	0.01	year + nNeg + fishmeth + us_tmin + Dist2Coast + headw_dist + lca + Mean7DayFlowMins + seg_june + FRE10.MaxDurBetween + FRE5.Count
Canterbury galaxias	5	0.585	0.01	year
Canterbury galaxias	5	0.742	0.01	year + nNeg + fishmeth + us_tmin + Dist2Coast + headw_dist + lca + Mean7DayFlowMins + FRE10.MaxDurBetween + FRE5.Count.
Canterbury galaxias	6	0.588	0.01	year
Canterbury galaxias	6	0.723	0.01	year + nNeg + fishmeth + us_tmin + Dist2Coast + headw_dist + lkur + Mean7DayFlowMaxs
Canterbury galaxias	7	0.585	0.01	year
Canterbury galaxias	7	0.745	0.009	year + nNeg + fishmeth + us_tmin + Dist2Coast + headw_dist + lca + Mean7DayFlowMins + seg_ro_mm + FRE10.MeanDurBetween
Canterbury galaxias	8	0.589	0.01	year

Species	Bootstrap	AUC	AUC S.D	Predictor code (see Table 2-2 for descriptions)
Canterbury galaxias	8	0.718	0.01	year + nNeg + fishmeth + us_tmin + Dist2Coast + headw_dist + lkur + Mean90DayFlowMaxs
Canterbury galaxias	9	0.589	0.01	year
Canterbury galaxias	9	0.743	0.01	year + fishmeth + us_tmin + Dist2Coast + seg_june + FRE5.Count + FRE10.MaxDurBetween. + lkur + headw_dist + Mean7DayFlowMaxs.
Canterbury galaxias	10	0.593	0.01	year
Canterbury galaxias	10	0.719	0.01	year + nNeg + fishmeth + us_tmin + Dist2Coast + headw_dist + lkur + Mean90DayFlowMaxs
Canterbury galaxias	11	0.588	0.01	year
Canterbury galaxias	11	0.722	0.01	year + nNeg + fishmeth + us_tmin + Dist2Coast + headw_dist + lkur + Mean90DayFlowMaxs.
Canterbury galaxias	12	0.592	0.01	year
Canterbury galaxias	12	0.727	0.01	year + nNeg + fishmeth + us_tmin + Dist2Coast + headw_dist + lkur + Mean90DayFlowMaxs
Canterbury galaxias	13	0.591	0.01	year
Canterbury galaxias	13	0.732	0.01	year + nNeg + fishmeth + us_tmin + Dist2Coast + headw_dist + lkur + Mean90DayFlowMaxs
Canterbury galaxias	14	0.587	0.01	year
Canterbury galaxias	14	0.718	0.01	year + nNeg + fishmeth + us_tmin + Dist2Coast + headw_dist + lkur + Mean90DayFlowMaxs
Canterbury galaxias	15	0.598	0.01	year
Canterbury galaxias	15	0.766	0.009	year + nNeg + fishmeth + us_tmin + Dist2Coast + headw_dist + lkur + FRE10.MaxDurBetween + FRE5.Count
Canterbury galaxias	16	0.596	0.01	year
Canterbury galaxias	16	0.74	0.01	year + nNeg + fishmeth + us_tmin + Dist2Coast + headw_dist + lkur + Mean90DayFlowMaxs
Canterbury galaxias	17	0.585	0.01	year
Canterbury galaxias	17	0.735	0.01	year + nNeg + fishmeth + us_tmin + Dist2Coast + headw_dist + lkur + Mean90DayFlowMaxs
Canterbury galaxias	18	0.584	0.01	year
Canterbury galaxias	18	0.721	0.01	year + nNeg + fishmeth + us_tmin + Dist2Coast + headw_dist + lkur + Mean90DayFlowMaxs
Canterbury galaxias	19	0.587	0.01	year
Canterbury galaxias	19	0.733	0.01	year + nNeg + fishmeth + us_tmin + Dist2Coast + seg_june + us_june + lkur + FRE10.MaxDurBetween. + FRE5.Count

Species	Bootstrap	AUC	AUC S.D	Predictor code (see Table 2-2 for descriptions)
Canterbury galaxias	20	0.587	0.011	year
Canterbury galaxias	20	0.734	0.01	year + nNeg + fishmeth + us_tmin + Dist2Coast + seg_june + us_rd25 + MeanPulseLengthLow+ us_ind_forest
Common bully	1	0.586	0.006	year
Common bully	1	0.681	0.006	year + seg_elev + StreamOrder + x3 + us_rnvar + fishmeth
Common bully	2	0.581	0.006	year
Common bully	2	0.671	0.006	year + seg_elev + us_rnvar + StreamOrder + x3 + fishmeth
Common bully	3	0.58	0.005	year
Common bully	3	0.684	0.006	year + seg_elev + StreamOrder + x3 + us_rnvar + fishmeth
Common bully	4	0.576	0.005	year
Common bully	4	0.689	0.006	year + seg_elev + seg_rnvar + StreamOrder + x3 + fishmeth
Common bully	5	0.583	0.006	year
Common bully	5	0.676	0.006	year + seg_elev + StreamOrder + x3 + us_rnvar + fishmeth
Common bully	6	0.581	0.006	year
Common bully	6	0.668	0.006	year + seg_elev + us_rnvar + StreamOrder + fishmeth + us_twarm
Common bully	7	0.578	0.005	year
Common bully	7	0.681	0.006	year + seg_elev + StreamOrder + x3 + us_rnvar + fishmeth
Common bully	8	0.576	0.005	year
Common bully	8	0.671	0.006	year + seg_elev + StreamOrder + x3 + us_rnvar + fishmeth
Common bully	9	0.58	0.005	year
Common bully	9	0.684	0.006	year + seg_elev + StreamOrder + us_rnvar + x3 + fishmeth
Common bully	10	0.582	0.006	year
Common bully	10	0.673	0.006	year + seg_elev + us_rnvar + StreamOrder + fishmeth + us_twarm
Common bully	11	0.57	0.005	year

Species	Bootstrap	AUC	AUC S.D	Predictor code (see Table 2-2 for descriptions)
Common bully	11	0.694	0.006	year + seg_elev + StreamOrder + us_penpet + fishmeth
Common bully	12	0.571	0.005	year
Common bully	12	0.685	0.006	year + seg_elev + StreamOrder + x3 + fishmeth + us_rnvar
Common bully	13	0.574	0.005	year
Common bully	13	0.691	0.006	year + seg_elev + StreamOrder + x3 + fishmeth + us_rnvar
Common bully	14	0.581	0.006	year
Common bully	14	0.694	0.006	year + seg_elev + seg_rnvar + StreamOrder + x3 + fishmeth
Common bully	15	0.579	0.005	year
Common bully	15	0.687	0.006	year + seg_elev + StreamOrder + us_rnvar + x3 + fishmeth
Common bully	16	0.569	0.005	year
Common bully	16	0.704	0.006	year + seg_elev + StreamOrder + us_penpet + fishmeth
Common bully	17	0.576	0.005	year
Common bully	17	0.68	0.006	year + seg_elev + StreamOrder + x3 + us_rnvar + fishmeth
Common bully	18	0.573	0.005	year
Common bully	18	0.679	0.006	year + seg_elev + seg_penpet + StreamOrder + fishmeth
Common bully	19	0.573	0.005	year
Common bully	19	0.681	0.006	year + seg_elev + StreamOrder + x3 + us_rnvar + fishmeth
Common bully	20	0.574	0.005	year
Common bully	20	0.688	0.006	year + seg_elev + us_rnvar + StreamOrder + x3 + fishmeth
Exotic	1	0.569	0.004	year
Exotic	1	0.716	0.004	year + us_tmin + org + DSav_slope + fishmeth + StreamOrder + Mean90DayFlowMaxs
Exotic	2	0.569	0.004	year
Exotic	2	0.716	0.004	year + us_tmin + StreamOrder + org + DSav_slope + fishmeth + Mean90DayFlowMaxs
Exotic	3	0.565	0.004	year
Exotic	3	0.713	0.004	year + us_tmin + StreamOrder + org + DSav_slope + fishmeth + Mean90DayFlowMaxs

Species	Bootstrap	AUC	AUC S.D	Predictor code (see Table 2-2 for descriptions)
Exotic	4	0.57	0.004	year
Exotic	4	0.712	0.004	year + us_tmin + StreamOrder + org + DSav_slope + fishmeth + Mean7DayFlowMaxs
Exotic	5	0.568	0.004	year
Exotic	5	0.709	0.004	year + us_tmin + StreamOrder + org + DSav_slope + fishmeth + Mean7DayFlowMaxs
Exotic	6	0.567	0.004	year
Exotic	6	0.714	0.004	year + us_tmin + org + DSav_slope + fishmeth + StreamOrder + Mean90DayFlowMaxs
Exotic	7	0.566	0.004	year
Exotic	7	0.711	0.004	year + us_tmin + StreamOrder + org + DSav_slope + fishmeth + Mean90DayFlowMaxs
Exotic	8	0.567	0.004	year
Exotic	8	0.716	0.004	year + us_tmin + StreamOrder + org + DSav_slope + fishmeth + Mean90DayFlowMaxs
Exotic	9	0.567	0.004	year
Exotic	9	0.717	0.004	year + us_tmin + org + StreamOrder + DSav_slope + fishmeth + Mean7DayFlowMaxs
Exotic	10	0.567	0.004	year
Exotic	10	0.711	0.004	year + us_tmin + StreamOrder + org + DSav_slope + fishmeth + Mean90DayFlowMaxs
Exotic	11	0.569	0.004	year
Exotic	11	0.708	0.004	year + us_tmin + StreamOrder + org + DSav_slope + fishmeth + Mean90DayFlowMaxs
Exotic	12	0.573	0.004	year
Exotic	12	0.71	0.004	year + us_tmin + StreamOrder + org + DSav_slope + fishmeth + Mean90DayFlowMaxs
Exotic	13	0.57	0.004	year
Exotic	13	0.716	0.004	year + us_tmin + org + StreamOrder + DSav_slope + fishmeth + Mean90DayFlowMaxs
Exotic	14	0.57	0.004	year
Exotic	14	0.709	0.004	year + us_tmin + org + DSav_slope + fishmeth + StreamOrder + Mean7DayFlowMaxs
Exotic	15	0.568	0.004	year
Exotic	15	0.713	0.004	year + us_tmin + StreamOrder + org + DSav_slope + fishmeth + Mean90DayFlowMaxs
Exotic	16	0.569	0.004	year
Exotic	16	0.717	0.004	year + us_tmin + StreamOrder + org + DSav_slope + fishmeth + Mean90DayFlowMaxs
Exotic	17	0.568	0.004	year
Exotic	17	0.71	0.004	year + us_tmin + org + DSav_slope + fishmeth + StreamOrder + Mean90DayFlowMaxs
Exotic	18	0.568	0.004	year

Species	Bootstrap	AUC	AUC S.D	Predictor code (see Table 2-2 for descriptions)
Exotic	18	0.712	0.004	year + us_tmin + StreamOrder + org + DSav_slope + fishmeth + Mean90DayFlowMaxs
Exotic	19	0.568	0.004	year
Exotic	19	0.715	0.004	year + us_tmin + StreamOrder + org + DSav_slope + fishmeth + Mean90DayFlowMaxs
Exotic	20	0.566	0.004	year
Exotic	20	0.71	0.004	year + us_tmin + StreamOrder + org + DSav_slope + fishmeth + Mean90DayFlowMaxs
Kōaro	1	0.541	0.005	year
Kōaro	1	0.694	0.007	year + l1 + seg_slope + DSav_slope + y3 + segshade + seg_penpet + fishmeth + DSDist2Lake + Dist2Coast
Kōaro	2	0.542	0.005	year
Kōaro	2	0.687	0.007	year + l1 + seg_slope + DSav_slope + y3 + segshade + seg_penpet + fishmeth
Kōaro	3	0.54	0.005	year
Kōaro	3	0.697	0.007	year + l1 + DSav_slope + us_slope + segshade + y3 + fishmeth + DSDist2Lake + Dist2Coast
Kōaro	4	0.539	0.005	year
Kōaro	4	0.691	0.007	year + l1 + seg_slope + DSav_slope + y3 + segshade + fishmeth + seg_penpet + DSDist2Lake + Dist2Coast
Kōaro	5	0.539	0.005	year
Kōaro	5	0.675	0.007	year + l1 + seg_slope + DSav_slope + y3 + segshade + fishmeth + seg_penpet
Kōaro	6	0.543	0.005	year
Kōaro	6	0.692	0.007	year + l1 + seg_slope + DSav_slope + y3 + segshade + seg_penpet + fishmeth + org + DSDist2Lake + Dist2Coast
Kōaro	7	0.544	0.005	year
Kōaro	7	0.699	0.007	year + l1 + seg_slope + DSav_slope + y3 + fishmeth + segshade + seg_penpet + DSDist2Lake + Dist2Coast
Kōaro	8	0.539	0.005	year
Kōaro	8	0.693	0.007	year + l1+ seg_slope + DSav_slope + y3 + segshade + fishmeth + seg_penpet + DSDist2Lake + Dist2Coast
Kōaro	9	0.541	0.005	year
Kōaro	9	0.69	0.007	year + l1 + seg_slope + DSav_slope + y3 + segshade + fishmeth + seg_penpet
Kōaro	10	0.542	0.005	year
Kōaro	10	0.692	0.007	year + l1 + seg_slope + DSav_slope + y3 + segshade + fishmeth + seg_penpet + DSDist2Lake + Dist2Coast
Kōaro	11	0.54	0.005	year
Kōaro	11	0.704	0.007	year + l1 + seg_slope + DSav_slope + y3 + segshade + fishmeth + seg_penpet + DSDist2Lake + Dist2Coast
Kōaro	12	0.542	0.005	year
Kōaro	12	0.675	0.007	year + l1 + seg_slope + DSav_slope + y3 + fishmeth + segshade + seg_penpet
Kōaro	13	0.544	0.005	year
Kōaro	13	0.691	0.007	year + l1+ seg_slope + DSav_slope + y3 + segshade + fishmeth + seg_penpet + DSDist2Lake + seg_tmin

Species	Bootstrap	AUC	AUC S.D	Predictor code (see Table 2-2 for descriptions)
Kōaro	14	0.539	0.005	year
Kōaro	14	0.692	0.007	year + l1+ seg_slope + DSav_slope + y3 + segshade + fishmeth + seg_penpet + DSDist2Lake + Dist2Coast
Kōaro	15	0.542	0.005	year
Kōaro	15	0.694	0.007	year l1 + seg_slope + DSav_slope + y3 + segshade + fishmeth + seg_penpet + DSDist2Lake + Dist2Coast
Kōaro	16	0.54	0.005	year
Kōaro	16	0.703	0.007	year + l1+ seg_slope + DSav_slope + y3 + segshade + fishmeth + seg_penpet + DSDist2Lake + Dist2Coast + org
Kōaro	17	0.542	0.005	year
Kōaro	17	0.699	0.007	year + l1+ seg_slope + DSav_slope + y3 + segshade + fishmeth + seg_penpet + org + DSDist2Lake + Dist2Coast
Kōaro	18	0.543	0.005	year
Kōaro	18	0.704	0.007	year + l1+ seg_slope + DSav_slope + y3 + segshade + fishmeth + seg_penpet + org + DSDist2Lake + Dist2Coast
Kōaro	19	0.539	0.005	year
Kōaro	19	0.68	0.007	year + l1+ seg_slope + DSav_slope + y3 + segshade + fishmeth + seg_penpet + org
Kōaro	20	0.542	0.005	year
Kōaro	20	0.676	0.007	year + l1+ seg_slope + DSav_slope + y3 + fishmeth + segshade + seg_penpet
Kōura	1	0.563	0.005	year
Kōura	1	0.678	0.005	year + seg_tmin + fishmeth + us_rnvar + headw_dist + org + x
Kōura	2	0.553	0.005	year
Kōura	2	0.676	0.005	year + seg_tmin + us_rnvar + fishmeth + headw_dist + org + x
Kōura	3	0.562	0.005	year
Kōura	3	0.69	0.005	year + seg_tmin + fishmeth + us_rnvar + headw_dist + org + x
Kōura	4	0.562	0.005	year
Kōura	4	0.689	0.005	year + seg_tmin + us_rnvar + fishmeth + headw_dist + org + x
Kōura	5	0.562	0.005	year
Kōura	5	0.688	0.005	year + seg_tmin + fishmeth + us_rnvar + headw_dist + org + x
Kōura	6	0.562	0.005	year
Kōura	6	0.699	0.005	year + seg_tmin + us_rnvar + fishmeth + headw_dist + org
Kōura	7	0.562	0.005	year
Kōura	7	0.678	0.005	year + seg_tmin + fishmeth + us_rnvar + headw_dist + org + x
Kōura	8	0.559	0.005	year
Kōura	8	0.685	0.005	year + seg_tmin + fishmeth + us_rnvar + headw_dist + org + x
Kōura	9	0.562	0.005	year
Kōura	9	0.68	0.005	year + seg_tmin + fishmeth + us_rnvar + headw_dist + org + x
Kōura	10	0.56	0.005	year
Kōura	10	0.689	0.005	year + seg_tmin + us_rnvar + fishmeth + headw_dist + org + x
Kōura	11	0.56	0.005	year
Kōura	11	0.69	0.005	year + seg_tmin + fishmeth + us_rnvar + headw_dist + org + x

Species	Bootstrap	AUC	AUC S.D	Predictor code (see Table 2-2 for descriptions)
Kōura	12	0.557	0.005	year
Kōura	12	0.689	0.005	year + seg_tmin + fishmeth + us_rnvar + headw_dist + org + x
Kōura	13	0.56	0.005	year
Kōura	13	0.695	0.005	year + seg_tmin + fishmeth + us_rnvar + headw_dist + org + x
Kōura	14	0.56	0.005	year
Kōura	14	0.684	0.005	year + seg_tmin + us_rnvar + fishmeth + headw_dist + org + x
Kōura	15	0.557	0.005	year
Kōura	15	0.685	0.005	year + seg_tmin + us_rnvar + fishmeth + headw_dist + org + x
Kōura	16	0.561	0.005	year
Kōura	16	0.687	0.005	year + seg_tmin + fishmeth + us_rnvar + headw_dist + org + x
Kōura	17	0.561	0.005	year
Kōura	17	0.682	0.005	year + seg_tmin + fishmeth + us_rnvar + headw_dist + org + x
Kōura	18	0.556	0.005	year
Kōura	18	0.688	0.005	year + seg_tmin + fishmeth + us_rnvar + headw_dist + org + x
Kōura	19	0.558	0.005	year
Kōura	19	0.689	0.005	year + seg_tmin + fishmeth + us_rnvar + headw_dist + org + x
Kōura	20	0.564	0.005	year
Kōura	20	0.679	0.005	year + seg_tmin + fishmeth + us_rnvar + headw_dist + org + x
longfin eel	1	0.596	0.004	year
longfin eel	1	0.753	0.004	year + nPos + fishmeth + org + DSDam+ us_elev + JulianMax
longfin eel	2	0.598	0.004	year
longfin eel	2	0.752	0.004	year + nPos+ seg_elev + fishmeth + org + DSDam+ x2
longfin eel	3	0.597	0.004	year
longfin eel	3	0.754	0.004	year + nPos+ fishmeth + org + DSDam+ us_elev + JulianMax
longfin eel	4	0.595	0.004	year
longfin eel	4	0.753	0.004	year + nPos+ fishmeth + org + DSDam+ us_elev + JulianMax
longfin eel	5	0.595	0.004	year
longfin eel	5	0.753	0.004	year + nPos+ fishmeth + org + DSDam+ us_elev + JulianMax
longfin eel	6	0.599	0.004	year
longfin eel	6	0.757	0.003	year + nPos+ fishmeth + org + DSDam+ us_elev + JulianMax
longfin eel	7	0.593	0.004	year
longfin eel	7	0.747	0.004	year + nPos+ fishmeth + org + DSDam+ us_elev + JulianMax
longfin eel	8	0.599	0.004	year
longfin eel	8	0.755	0.004	year + nPos+ fishmeth + org + DSDam+ us_elev + JulianMax
longfin eel	9	0.595	0.004	year
longfin eel	9	0.751	0.004	year + nPos+ fishmeth + org + DSDam+ us_elev + JulianMax
longfin eel	10	0.596	0.004	year
longfin eel	10	0.744	0.004	year + nPos+ fishmeth + org + DSDam+ us_elev + JulianMax
longfin eel	11	0.595	0.004	year

Species	Bootstrap	AUC	AUC S.D	Predictor code (see Table 2-2 for descriptions)
longfin eel	11	0.75	0.004	year + nPos+ seg_elev + fishmeth + org + DSDam+ x2
longfin eel	12	0.596	0.004	year
longfin eel	12	0.755	0.003	year + nPos+ fishmeth + org + DSDam+ us_elev + JulianMax
longfin eel	13	0.595	0.004	year
longfin eel	13	0.756	0.004	year + nPos+ fishmeth + org + DSDam+ us_elev + JulianMax
longfin eel	14	0.597	0.004	year
longfin eel	14	0.753	0.004	year + nPos+ fishmeth + org + DSDam+ us_elev + JulianMax
longfin eel	15	0.594	0.004	year
longfin eel	15	0.751	0.004	year + nPos+ fishmeth + org + DSDam+ us_elev + JulianMax
longfin eel	16	0.597	0.004	year
longfin eel	16	0.745	0.004	year + nPos+ fishmeth + org + DSDam+ us_elev
longfin eel	17	0.598	0.004	year
longfin eel	17	0.75	0.004	year + nPos+ fishmeth + org + DSDam+ us_elev + JulianMax
longfin eel	18	0.598	0.004	year
longfin eel	18	0.744	0.004	year + nPos+ fishmeth + org + DSDam+ us_elev
longfin eel	19	0.597	0.004	year
longfin eel	19	0.749	0.004	year + nPos+ seg_elev + fishmeth + org + DSDam+ x2
longfin eel	20	0.594	0.004	year
longfin eel	20	0.749	0.004	year + nPos+ seg_elev + fishmeth + org + DSDam+ x2
Native	1	0.566	0.005	year
Native	1	0.699	0.005	year + seg_tmin + fishmeth + Dist2Coast + nNeg + DSmax_slope + org
Native	2	0.564	0.005	year
Native	2	0.709	0.005	year + seg_tmin + fishmeth + Dist2Coast + Reversals+ DSmax_slope + MeanPulseLengthLow+ org
Native	3	0.565	0.005	year
Native	3	0.707	0.005	year + seg_tmin + fishmeth + Dist2Coast + MeanPulseLengthLow+ DSmax_slope + Reversals+ org
Native	4	0.561	0.005	year
Native	4	0.704	0.005	year + seg_tmin + fishmeth + Dist2Coast + nNeg + DSmax_slope + org
Native	5	0.564	0.005	year
Native	5	0.707	0.005	year + seg_tmin + fishmeth + Dist2Coast + MeanPulseLengthLow+ meanNeg + DSmax_slope + org
Native	6	0.564	0.005	year
Native	6	0.707	0.005	year + seg_tmin + fishmeth + Dist2Coast + Reversals+ DSmax_slope + MeanPulseLengthLow+ org
Native	7	0.562	0.005	year
Native	7	0.704	0.004	year + seg_tmin + fishmeth + Dist2Coast + Reversals+ DSmax_slope + MeanPulseLengthLow+ org
Native	8	0.561	0.005	year
Native	8	0.704	0.005	year + seg_tmin + fishmeth + Dist2Coast + MeanPulseLengthLow+ DSmax_slope + org + Reversals

Species	Bootstrap	AUC	AUC S.D	Predictor code (see Table 2-2 for descriptions)
Native	9	0.562	0.005	year
Native	9	0.71	0.005	year + seg_tmin + fishmeth + Dist2Coast + MeanPulseLengthLow+ DSmax_slope + org + Reversals
Native	10	0.561	0.005	year
Native	10	0.705	0.005	year + seg_tmin + fishmeth + Dist2Coast + MeanPulseLengthLow+ meanNeg + DSmax_slope + org
Native	11	0.564	0.005	year
Native	11	0.705	0.005	year + seg_tmin + fishmeth + Dist2Coast + nNeg + DSmax_slope + org
Native	12	0.563	0.005	year
Native	12	0.707	0.004	year + seg_tmin + fishmeth + Dist2Coast + MeanPulseLengthLow+ DSmax_slope + org + Reversals
Native	13	0.566	0.005	year
Native	13	0.71	0.005	year + seg_tmin + fishmeth + Dist2Coast + MeanPulseLengthLow+ DSmax_slope + org + Reversals
Native	14	0.56	0.005	year
Native	14	0.708	0.005	year + seg_tmin + fishmeth + Dist2Coast + Reversals+ DSmax_slope + MeanPulseLengthLow+ org
Native	15	0.565	0.005	year
Native	15	0.703	0.005	year + seg_tmin + fishmeth + Dist2Coast + nNeg + DSmax_slope + org
Native	16	0.561	0.005	year
Native	16	0.704	0.004	year + seg_tmin + fishmeth + Dist2Coast + Reversals+ DSmax_slope + MeanPulseLengthLow+ org
Native	17	0.564	0.005	year
Native	17	0.703	0.005	year + seg_tmin + fishmeth + Dist2Coast + Reversals+ DSmax_slope + org + MeanPulseLengthLow
Native	18	0.561	0.005	year
Native	18	0.703	0.004	year + seg_tmin + fishmeth + Dist2Coast + Reversals+ DSmax_slope + MeanPulseLengthLow+ org
Native	19	0.561	0.005	year
Native	19	0.71	0.005	year + seg_tmin + fishmeth + Dist2Coast + MeanPulseLengthLow+ DSmax_slope + org + Reversals
Native	20	0.562	0.005	year
Native	20	0.708	0.005	year + seg_tmin + fishmeth + Dist2Coast + MeanPulseLengthLow+ meanNeg + DSmax_slope + org
Rainbow trout	1	0.601	0.008	year
Rainbow trout	1	0.719	0.008	year + nPos+ DSDist2Lake + org + fishmeth + FRE5.MeanDurBetween + x3 + us_elev + Contingency
Rainbow trout	2	0.607	0.008	year
Rainbow trout	2	0.752	0.008	year + nPos+ DSDist2Lake + org + fishmeth + FRE5.MeanDurBetween + x3 + us_elev + Contingency
Rainbow trout	3	0.595	0.008	year

Species	Bootstrap	AUC	AUC S.D	Predictor code (see Table 2-2 for descriptions)
Rainbow trout	3	0.75	0.008	year + nPos+ DSDist2Lake + x3 + fishmeth + org + us_elev + Contingency + FRE5.Count
Rainbow trout	4	0.585	0.008	year
Rainbow trout	4	0.746	0.008	year + nPos+ DSDist2Lake + org + fishmeth + x3 + us_elev + Contingency + FRE5.Count + seg_rain
Rainbow trout	5	0.587	0.008	year
Rainbow trout	5	0.751	0.008	year + nPos+ DSDist2Lake + org + fishmeth + FRE5.MeanDurBetween + x3 + us_elev + Contingency
Rainbow trout	6	0.592	0.008	year
Rainbow trout	6	0.739	0.008	year + nPos+ DSDist2Lake + org + fishmeth + FRE5.MeanDurBetween + x3 + us_elev + Contingency
Rainbow trout	7	0.594	0.008	year
Rainbow trout	7	0.749	0.008	year + nPos+ DSDist2Lake + org + fishmeth + FRE5.MeanDurBetween + x3 + us_elev + Contingency
Rainbow trout	8	0.599	0.008	year
Rainbow trout	8	0.739	0.008	year + nPos+ DSDist2Lake + org + fishmeth + FRE5.MeanDurBetween + x3 + us_elev + Contingency
Rainbow trout	9	0.593	0.008	year
Rainbow trout	9	0.722	0.008	year + nPos+ DSDist2Lake + org + fishmeth + x3 + us_elev + Contingency + FRE5.Count + seg_rain
Rainbow trout	10	0.589	0.008	year
Rainbow trout	10	0.744	0.008	year + nPos+ DSDist2Lake + org + fishmeth + x3 + us_elev + Contingency + FRE5.Count
Rainbow trout	11	0.597	0.008	year
Rainbow trout	11	0.726	0.008	year + nPos+ DSDist2Lake + org + fishmeth + FRE5.MeanDurBetween + x3 + us_elev + Contingency
Rainbow trout	12	0.598	0.008	year
Rainbow trout	12	0.742	0.008	year + nPos+ DSDist2Lake + org + fishmeth + FRE5.MeanDurBetween + x3 + us_elev + Contingency
Rainbow trout	13	0.594	0.008	year
Rainbow trout	13	0.753	0.008	year + nPos+ DSDist2Lake + org + fishmeth + FRE5.MeanDurBetween + x3 + us_elev + Contingency
Rainbow trout	14	0.594	0.008	year
Rainbow trout	14	0.758	0.008	year + nPos+ DSDist2Lake + org + fishmeth + FRE5.MeanDurBetween + x3 + us_elev + Contingency

Species	Bootstrap	AUC	AUC S.D	Predictor code (see Table 2-2 for descriptions)
Rainbow trout	15	0.596	0.008	year
Rainbow trout	15	0.75	0.008	year + nPos+ DSDist2Lake + org + fishmeth + FRE5.MeanDurBetween + x3 + us_elev + Contingency
Rainbow trout	16	0.598	0.008	year
Rainbow trout	16	0.752	0.008	year + nPos+ DSDist2Lake + org + fishmeth + FRE5.MeanDurBetween + x3 + us_elev + Contingency
Rainbow trout	17	0.607	0.008	year
Rainbow trout	17	0.752	0.008	year + nPos+ DSDist2Lake + org + fishmeth + FRE5.MeanDurBetween + x3 + us_elev + Contingency
Rainbow trout	18	0.597	0.008	year
Rainbow trout	18	0.737	0.008	year + nPos+ DSDist2Lake + org + fishmeth + FRE5.MeanDurBetween + x3 + us_elev + Contingency
Rainbow trout	19	0.598	0.008	year
Rainbow trout	19	0.737	0.008	year + meanNeg + nNeg + DSDist2Lake + org + fishmeth + x3 + us_elev + Contingency
Rainbow trout	20	0.595	0.008	year
Rainbow trout	20	0.731	0.008	year + nPos+ DSDist2Lake + org + fishmeth + x3 + us_elev + Contingency + FRE5.Count + seg_rain
Redfin bully	1	0.575	0.006	year
Redfin bully	1	0.802	0.005	year + Dist2Coast + nNeg + Constancy + fishmeth + seg_tmin + us_slope + us_elev + org + us_penpet
Redfin bully	2	0.569	0.005	year
Redfin bully	2	0.806	0.005	year + Dist2Coast + fishmeth + seg_tmin + us_slope + us_elev + org + nNeg + us_penpet + Constancy
Redfin bully	3	0.572	0.005	year
Redfin bully	3	0.803	0.005	year + Dist2Coast + nNeg + Constancy + fishmeth + seg_tmin + us_slope + us_elev + org + us_penpet
Redfin bully	4	0.577	0.006	year
Redfin bully	4	0.81	0.005	year + Dist2Coast + fishmeth + seg_tmin + us_slope + us_elev + org + nNeg + us_penpet + Constancy
Redfin bully	5	0.576	0.006	year
Redfin bully	5	0.806	0.005	year + Dist2Coast + nNeg + Constancy + fishmeth + seg_tmin + us_slope + us_elev + org + us_penpet
Redfin bully	6	0.568	0.005	year
Redfin bully	6	0.801	0.005	year + Dist2Coast + nNeg + fishmeth + seg_tmin + us_slope + us_elev + us_penpet + org + Constancy
Redfin bully	7	0.57	0.005	year
Redfin bully	7	0.793	0.005	year + Dist2Coast + nNeg + Constancy + fishmeth + seg_tmin + us_slope + us_elev + org + us_penpet
Redfin bully	8	0.575	0.006	year

Species	Bootstrap	AUC	AUC S.D	Predictor code (see Table 2-2 for descriptions)
Redfin bully	8	0.81	0.005	year + Dist2Coast + nNeg + Constancy + fishmeth + seg_tmin + us_slope + us_elev + org + us_penpet + DSDam
Redfin bully	9	0.576	0.006	year
Redfin bully	9	0.788	0.005	year + Dist2Coast + fishmeth + seg_tmin + us_slope + us_elev + org + nNeg + us_penpet + Constancy
Redfin bully	10	0.573	0.005	year
Redfin bully	10	0.783	0.005	year + Dist2Coast + nNeg + Constancy + fishmeth + seg_tmin + us_slope + us_elev + org + us_penpet
Redfin bully	11	0.573	0.006	year
Redfin bully	11	0.78	0.006	year + Dist2Coast + nNeg + Constancy + fishmeth + seg_tmin + us_slope + us_elev + org + us_penpet
Redfin bully	12	0.583	0.006	year
Redfin bully	12	0.795	0.005	year + Dist2Coast + nNeg + Constancy + fishmeth + seg_tmin + us_slope + us_elev + org + us_penpet
Redfin bully	13	0.581	0.006	year
Redfin bully	13	0.799	0.005	year + Dist2Coast + nNeg + fishmeth + seg_tmin + us_slope + us_elev + us_penpet + org + Constancy
Redfin bully	14	0.572	0.005	year
Redfin bully	14	0.802	0.005	year + Dist2Coast + fishmeth + seg_tmin + us_slope + us_elev + org + nNeg + us_penpet + Constancy
Redfin bully	15	0.579	0.006	year
Redfin bully	15	0.781	0.005	year + Dist2Coast + fishmeth + seg_tmin + us_slope + us_elev + org + nNeg + us_penpet + Constancy
Redfin bully	16	0.574	0.005	year
Redfin bully	16	0.796	0.005	year + Dist2Coast + nNeg + Constancy + fishmeth + seg_tmin + us_slope + us_elev + org + us_penpet
Redfin bully	17	0.569	0.005	year
Redfin bully	17	0.81	0.005	year + Dist2Coast + nNeg + Constancy + fishmeth + seg_tmin + us_slope + us_elev + org + us_penpet
Redfin bully	18	0.568	0.005	year
Redfin bully	18	0.806	0.005	year + Dist2Coast + fishmeth + seg_tmin + us_slope + Predictability + us_elev + org + nNeg + us_penpet
Redfin bully	19	0.581	0.006	year
Redfin bully	19	0.804	0.005	year + Dist2Coast + fishmeth + seg_tmin + us_slope + us_elev + Mean90DayFlowMins + org + nNeg + us_penpet + DSDam
Redfin bully	20	0.576	0.006	year
Redfin bully	20	0.803	0.005	year + Dist2Coast + nNeg + fishmeth + seg_tmin + us_slope + us_elev + org + us_penpet
Shortfin eel	1	0.543	0.005	year
Shortfin eel	1	0.753	0.005	year + us_twarm + org + seg_elev + fishmeth + segshade
Shortfin eel	2	0.535	0.004	year
Shortfin eel	2	0.762	0.005	year + us_twarm + org + seg_elev + fishmeth + segshade
Shortfin eel	3	0.535	0.004	year

Species	Bootstrap	AUC	AUC S.D	Predictor code (see Table 2-2 for descriptions)
Shortfin eel	3	0.758	0.005	year + us_twarm + org + seg_elev + fishmeth + segshade
Shortfin eel	4	0.541	0.005	year
Shortfin eel	4	0.751	0.005	year + us_twarm + org + seg_elev + fishmeth + segshade
Shortfin eel	5	0.539	0.005	year
Shortfin eel	5	0.745	0.005	year + us_twarm + org + seg_elev + fishmeth + segshade
Shortfin eel	6	0.54	0.005	year
Shortfin eel	6	0.758	0.005	year + us_twarm + org + seg_elev + fishmeth + segshade
Shortfin eel	7	0.545	0.005	year
Shortfin eel	7	0.759	0.005	year + us_twarm + org + seg_elev + fishmeth + segshade
Shortfin eel	8	0.539	0.005	year
Shortfin eel	8	0.76	0.005	year + us_twarm + org + seg_elev + fishmeth + segshade
Shortfin eel	9	0.543	0.005	year
Shortfin eel	9	0.753	0.005	year + us_twarm + org + seg_elev + fishmeth + segshade
Shortfin eel	10	0.541	0.005	year
Shortfin eel	10	0.757	0.005	year + us_twarm + org + seg_elev + fishmeth + segshade
Shortfin eel	11	0.543	0.005	year
Shortfin eel	11	0.756	0.005	year + us_twarm + org + seg_elev + fishmeth + segshade
Shortfin eel	12	0.542	0.005	year
Shortfin eel	12	0.761	0.005	year + us_twarm + org + seg_elev + fishmeth + segshade
Shortfin eel	13	0.536	0.005	year
Shortfin eel	13	0.762	0.005	year + us_twarm + org + seg_elev + fishmeth + segshade
Shortfin eel	14	0.539	0.005	year
Shortfin eel	14	0.754	0.005	year + us_twarm + org + seg_elev + fishmeth + segshade
Shortfin eel	15	0.534	0.004	year
Shortfin eel	15	0.759	0.005	year + us_twarm + org + seg_elev + fishmeth + segshade
Shortfin eel	16	0.541	0.005	year
Shortfin eel	16	0.755	0.005	year + us_twarm + org + seg_elev + fishmeth + segshade
Shortfin eel	17	0.539	0.005	year
Shortfin eel	17	0.766	0.005	year + us_twarm + org + seg_elev + fishmeth + segshade
Shortfin eel	18	0.534	0.004	year
Shortfin eel	18	0.753	0.005	year + us_twarm + org + seg_elev + fishmeth + segshade
Shortfin eel	19	0.539	0.005	year
Shortfin eel	19	0.757	0.005	year + us_twarm + org + seg_elev + fishmeth + segshade
Shortfin eel	20	0.537	0.004	year
Shortfin eel	20	0.754	0.005	year + us_twarm + org + seg_elev + fishmeth + segshade
Torrent fish	1	0.564	0.006	year
Torrent fish	1	0.74	0.007	year + seg_elev + us_slope + fishmeth + StreamOrder + xy2 + L2 + seg_rnvar + DSDam+ org
Torrent fish	2	0.557	0.006	year

Species	Bootstrap	AUC	AUC S.D	Predictor code (see Table 2-2 for descriptions)
Torrent fish	2	0.736	0.008	year + seg_elev + us_slope + fishmeth + StreamOrder + xy2 + L2 + seg_rnvar + DSDam+ us_LakeArea
Torrent fish	3	0.558	0.006	year
Torrent fish	3	0.74	0.008	year + seg_elev + us_slope + fishmeth + StreamOrder + xy2 + L2 + seg_rnvar + DSDam+ org
Torrent fish	4	0.561	0.006	year
Torrent fish	4	0.736	0.007	year + nNeg + seg_elev + fishmeth + DSDam+ xy2 + us_elev + org + seg_ro_mm + StreamOrder
Torrent fish	5	0.556	0.006	year
Torrent fish	5	0.733	0.007	year + seg_elev + us_slope + fishmeth + StreamOrder + xy2 + L2 + seg_rnvar + DSDam+ org
Torrent fish	6	0.553	0.005	year
Torrent fish	6	0.733	0.007	year + seg_elev + us_slope + fishmeth + StreamOrder + xy2 + L2 + seg_rnvar + DSDam+ org
Torrent fish	7	0.561	0.006	year
Torrent fish	7	0.736	0.007	year + seg_elev + us_slope + fishmeth + StreamOrder + xy2 + L2 + seg_rnvar + DSDam
Torrent fish	8	0.557	0.006	year
Torrent fish	8	0.726	0.007	year + seg_elev + us_slope + fishmeth + StreamOrder + xy2 + L2 + seg_rnvar + DSDam
Torrent fish	9	0.563	0.006	year
Torrent fish	9	0.728	0.007	year + seg_elev + us_slope + fishmeth + StreamOrder + xy2 + L2 + seg_rnvar + DSDam+ org
Torrent fish	10	0.556	0.006	year
Torrent fish	10	0.738	0.008	year + seg_elev + us_slope + fishmeth + StreamOrder + xy2 + L2 + seg_rnvar + DSDam+ org
Torrent fish	11	0.562	0.006	year
Torrent fish	11	0.713	0.007	year + seg_elev + us_slope + fishmeth + StreamOrder + xy2 + L2 + seg_rnvar + DSDam+ org
Torrent fish	12	0.555	0.006	year
Torrent fish	12	0.733	0.008	year + seg_elev + us_slope + fishmeth + StreamOrder + xy2 + L2 + seg_rnvar + DSDam+ org
Torrent fish	13	0.569	0.006	year
Torrent fish	13	0.738	0.007	year + seg_elev + us_slope + fishmeth + StreamOrder + xy2 + L2 + seg_rnvar + DSDam+ org
Torrent fish	14	0.57	0.006	year
Torrent fish	14	0.725	0.008	year + seg_elev + us_slope + fishmeth + StreamOrder + xy2 + L2 + seg_rnvar + DSDam+ org
Torrent fish	15	0.559	0.006	year
Torrent fish	15	0.73	0.007	year + seg_elev + us_slope + fishmeth + StreamOrder + xy2 + L2 + seg_rnvar + DSDam
Torrent fish	16	0.56	0.006	year
Torrent fish	16	0.733	0.007	year + seg_elev + us_slope + fishmeth + StreamOrder + xy2 + L2 + seg_rnvar + DSDam+ org

Species	Bootstrap	AUC	AUC S.D	Predictor code (see Table 2-2 for descriptions)
Torrent fish	17	0.558	0.006	year
Torrent fish	17	0.728	0.007	year + seg_elev + us_slope + fishmeth + StreamOrder + xy2 + L2 + seg_rnvar + DSDam
Torrent fish	18	0.558	0.006	year
Torrent fish	18	0.719	0.007	year + seg_elev + us_slope + fishmeth + StreamOrder + xy2 + L2 + seg_rnvar + DSDam
Torrent fish	19	0.568	0.006	year
Torrent fish	19	0.747	0.008	year + nNeg + seg_elev + fishmeth + DSDam+ xy2 + us_elev + org + seg_ro_mm + StreamOrder + us_LakeArea
Torrent fish	20	0.567	0.006	year
Torrent fish	20	0.719	0.007	year + seg_elev + us_slope + fishmeth + StreamOrder + xy2 + L2 + seg_rnvar + DSDam+ org
Upland bully	1	0.563	0.006	year
Upland bully	1	0.713	0.006	year + fishmeth + Segslpmean + seg_rd100 + nNeg + Contingency + org + seg_penpet + DSav_slope + USCalcium
Upland bully	2	0.561	0.006	year
Upland bully	2	0.702	0.006	year + fishmeth + Segslpmean + seg_rd100 + nNeg + Contingency + seg_penpet + DSav_slope + org
Upland bully	3	0.562	0.006	year
Upland bully	3	0.703	0.006	year + fishmeth + Segslpmean + seg_rd100 + Contingency + nNeg + seg_penpet + DSav_slope + org
Upland bully	4	0.562	0.006	year
Upland bully	4	0.694	0.006	year + Segslpmean + fishmeth + DSmax_slope + seg_rd100 + nNeg + seg_penpet + seg_tmin + org + seg_elev
Upland bully	5	0.556	0.006	year
Upland bully	5	0.713	0.006	year + DSmax_slope + fishmeth + Segslpmean + seg_rd100 + Contingency + nNeg + DSDist2Lake + seg_penpet + Mean1DayFlowMaxs + org
Upland bully	6	0.557	0.006	year
Upland bully	6	0.679	0.006	year + StreamOrder + fishmeth + DSmax_slope + Reversals+ us_tmin + us_twarm + headw_dist + meanNeg
Upland bully	7	0.561	0.006	year
Upland bully	7	0.7	0.006	year + DSmax_slope + fishmeth + Segslpmean + seg_rd100 + nNeg + seg_penpet + seg_tmin + org + seg_elev
Upland bully	8	0.56	0.006	year
Upland bully	8	0.687	0.006	year + DSmax_slope + fishmeth + Segslpmean + seg_rd100 + nNeg + seg_tmin + us_twarm + StreamOrder
Upland bully	9	0.558	0.006	year
Upland bully	9	0.701	0.006	year + DSmax_slope + fishmeth + Segslpmean + seg_rd100 + nNeg + seg_penpet + seg_tmin + seg_elev + org
Upland bully	10	0.561	0.006	year
Upland bully	10	0.705	0.006	year + DSmax_slope + fishmeth + Segslpmean + seg_rd100 + nNeg + seg_penpet + org + seg_tmin + seg_elev
Upland bully	11	0.561	0.006	year

| Species	Bootstrap	AUC	AUC S.D	Predictor code (see Table 2-2 for descriptions)
Upland bully	11	0.693	0.006	year + DSmax_slope + Reversals+ fishmeth + Segslpmean + seg_rd100 + nNeg + DSDist2Lake + Contingency
Upland bully	12	0.56	0.006	year
Upland bully	12	0.709	0.006	year + DSmax_slope + fishmeth + Segslpmean + seg_rd100 + Contingency + nNeg + DSDist2Lake + Mean1DayFlowMaxs + us_penpet + org
Upland bully	13	0.561	0.006	year
Upland bully	13	0.688	0.006	year + DSmax_slope + fishmeth + Segslpmean + seg_rd100 + nNeg + DSDist2Lake + Contingency + FRE5.MeanDurBetween + org
Upland bully	14	0.561	0.006	year
Upland bully	14	0.706	0.006	year + DSmax_slope + Reversals+ fishmeth + Segslpmean + seg_rd100 + Contingency + JulianMax + org + nNeg + DSDist2Lake
Upland bully	15	0.557	0.006	year
Upland bully	15	0.706	0.006	year + fishmeth + Segslpmean + seg_rd100 + nNeg + Contingency + seg_penpet + DSav_slope + org
Upland bully	16	0.559	0.006	year
Upland bully	16	0.707	0.006	year + fishmeth + Segslpmean + seg_rd100 + nNeg + Contingency + seg_penpet + DSav_slope + org
Upland bully	17	0.56	0.006	year
Upland bully	17	0.695	0.006	year + fishmeth + DSmax_slope + us_tmin + us_twarm + meanNeg + MeanPulseLengthLow+ FRE1.Count + DSDist2Lake + Contingency
Upland bully	18	0.564	0.006	year
Upland bully	18	0.699	0.006	year + DSmax_slope + fishmeth + Segslpmean + seg_rd100 + nNeg + org + seg_penpet + seg_tmin + seg_elev
Upland bully	19	0.559	0.006	year
Upland bully	19	0.706	0.006	year + fishmeth + Segslpmean + seg_rd100 + nNeg + Contingency + seg_penpet + DSav_slope + org
Upland bully	20	0.561	0.006	year
Upland bully	20	0.7	0.006	year + fishmeth + Segslpmean + seg_rd100 + Contingency + nNeg + seg_penpet + DSav_slope + org

Appendix C   Raw Sen slope results

These are raw Sen slope results and slopes have not been converted to %/year (as is presented in Section 3). Species are ordered alphabetically within each time period.

Time period	Species	Intercept	Slope	CI Include zero	Lower CI	Upper CI	Intercept	Slope	CI Include zero	Lower CI	Upper CI
				Unweighted					**weighted**		
1977–2015	Brown trout	6.3522	-0.0031	FALSE	-0.0035	-0.0028	9.0294	-0.0044	FALSE	-0.0048	-0.0041
	Canterbury galaxias	2.6859	-0.0012	FALSE	-0.0022	-0.0005	7.3296	-0.0036	FALSE	-0.0045	-0.0027
	Common bully	3.1786	-0.0016	FALSE	-0.0017	-0.0014	4.4848	-0.0022	FALSE	-0.0024	-0.0020
	Exotic fish	4.5380	-0.0021	FALSE	-0.0026	-0.0016	7.7100	-0.0037	FALSE	-0.0043	-0.0034
	Kōaro	0.2047	-0.0001	TRUE	-0.0002	0	0.9761	-0.0005	FALSE	-0.0007	-0.0003
	Kōura	-0.6968	0.0004	FALSE	0.0002	0.0007	0.6163	-0.0002	TRUE	-0.0006	0.0001
	Longfin eel	0.1548	0.0001	TRUE	-0.0006	0.0009	2.1717	-0.0009	FALSE	-0.0017	-0.0003
	Native fish	0.1275	0.0004	FALSE	0.0001	0.0006	-1.0176	0.0009	FALSE	0.0006	0.0013
	Rainbow trout	2.9177	-0.0014	FALSE	-0.0016	-0.0012	4.3298	-0.0021	FALSE	-0.0025	-0.0016
	Redfin bully	0.1429	-0.0001	TRUE	-0.0001	0	0.0903	0	TRUE	-0.0001	0
	Shortfin eel	-2.4899	0.0013	FALSE	0.0011	0.0014	-3.5246	0.0018	FALSE	0.0017	0.0019
	Torrent fish	-0.1738	0.0001	TRUE	0	0.0002	-0.1467	0.0001	TRUE	-0.0001	0.0002
	Upland bully	-6.9578	0.0036	FALSE	0.0031	0.0043	-6.7261	0.0035	FALSE	0.0026	0.0042
1977–1994	Brown trout	7.5259	-0.0037	FALSE	-0.0060	-0.0006	18.3981	-0.0092	FALSE	-0.0132	-0.0079
	Canterbury galaxias	9.7497	-0.0048	TRUE	-0.0070	0.0003	10.6039	-0.0052	TRUE	-0.0102	0.0021
	Common bully	1.3027	-0.0006	TRUE	-0.0013	0.0012	6.3320	-0.0031	FALSE	-0.0046	-0.0013
	Exotic fish	17.9514	-0.0089	FALSE	-0.0114	-0.0062	26.4156	-0.0132	FALSE	-0.0151	-0.0114
	Kōaro	-0.3282	0.0002	TRUE	-0.0004	0.0010	1.0754	-0.0005	TRUE	-0.0012	0.0003
	Kōura	1.6321	-0.0008	TRUE	-0.0025	0.0009	9.2901	-0.0046	FALSE	-0.0062	-0.0031
	Longfin eel	-12.4630	0.0064	FALSE	0.0039	0.0097	-8.1963	0.0043	FALSE	0.0005	0.0080
	Native fish	-4.5033	0.0027	FALSE	0.0013	0.0053	-10.7333	0.0058	FALSE	0.0041	0.0069
	Rainbow trout	5.7679	-0.0029	FALSE	-0.0032	-0.0024	14.5321	-0.0073	FALSE	-0.0109	-0.0065
	Redfin bully	0.0960	0.0000	TRUE	-0.0002	0.0002	-0.5618	0.0003	TRUE	-0.0003	0.0006
	Shortfin eel	-0.8239	0.0004	TRUE	0	0.0009	0.7716	-0.0004	TRUE	-0.0010	0.0003
	Torrent fish	-1.7570	0.0009	FALSE	0.0006	0.0013	-1.9620	0.0010	FALSE	0.0003	0.0017
	Upland bully	-11.8992	0.0061	FALSE	0.0046	0.0073	-18.5871	0.0094	FALSE	0.0085	0.0105
1995-2015	Brown trout	6.1806	-0.0030	FALSE	-0.0039	-0.0024	6.3544	-0.0031	FALSE	-0.0043	-0.0019

Time period	Species	Unweighted					weighted				
		Intercept	Slope	CI Include zero	Lower CI	Upper CI	Intercept	Slope	CI Include zero	Lower CI	Upper CI
	Canterbury galaxias	14.7777	-0.0073	FALSE	-0.0124	-0.0035	16.3864	-0.0081	FALSE	-0.0156	-0.0035
	Common bully	1.1812	-0.0006	FALSE	-0.0007	-0.0004	0.3723	-0.0002	TRUE	-0.0005	0.0001
	Exotic fish	1.3573	-0.0005	TRUE	-0.0016	0.0005	-0.7395	0.0005	TRUE	-0.0009	0.0017
	Kōaro	2.0747	-0.0010	FALSE	-0.0015	-0.0007	1.2063	-0.0006	TRUE	-0.0010	0.0003
	Kōura	1.7485	-0.0008	FALSE	-0.0020	-0.0001	-0.3606	0.0002	TRUE	-0.0008	0.0010
	Longfin eel	3.6533	-0.0017	TRUE	-0.0040	0.0012	-5.1108	0.0027	TRUE	-0.0003	0.0049
	Native fish	0.0812	0.0004	TRUE	-0.0007	0.0013	2.1949	-0.0007	TRUE	-0.0017	0.0012
	Rainbow trout	-1.8710	0.0010	FALSE	0.0004	0.0014	-4.6829	0.0024	FALSE	0.0016	0.0031
	Redfin bully	0.3716	-0.0002	FALSE	-0.0003	-0.0001	0.0722	0	TRUE	-0.0001	0.0001
	Shortfin eel	-4.4999	0.0023	FALSE	0.0019	0.0026	-6.4691	0.0033	FALSE	0.0028	0.0038
	Torrent fish	-0.2754	0.0002	TRUE	-0.0003	0.0005	-2.5716	0.0013	FALSE	0.0009	0.0020
	Upland bully	1.7691	-0.0008	TRUE	-0.0030	0.0009	1.6273	-0.0007	TRUE	-0.0030	0.0018

Appendix D   Fitted Sen slope results

These Sen slope results are fitted to the characteristic probability of capture for each year (black circles) and 95% CI (grey shaded area) for each species.
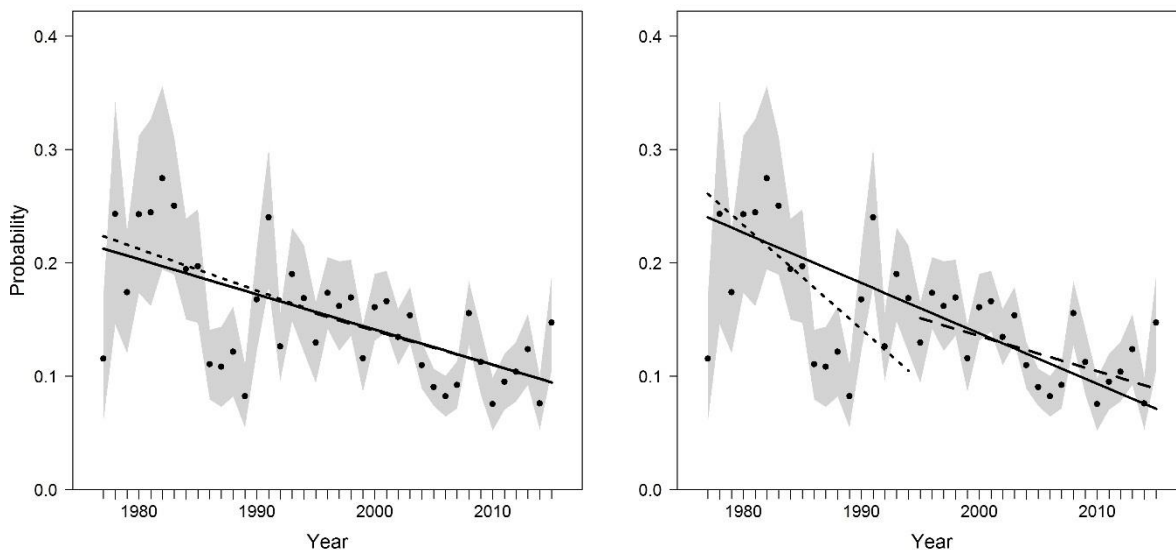
Brown trout Sen slope results for 1977–2015 (solid black line), 1977–1994 (dotted black line) and 1995-2015 (dashed black line). SSE and results are shown on the left, while WSSE are shown on the right.
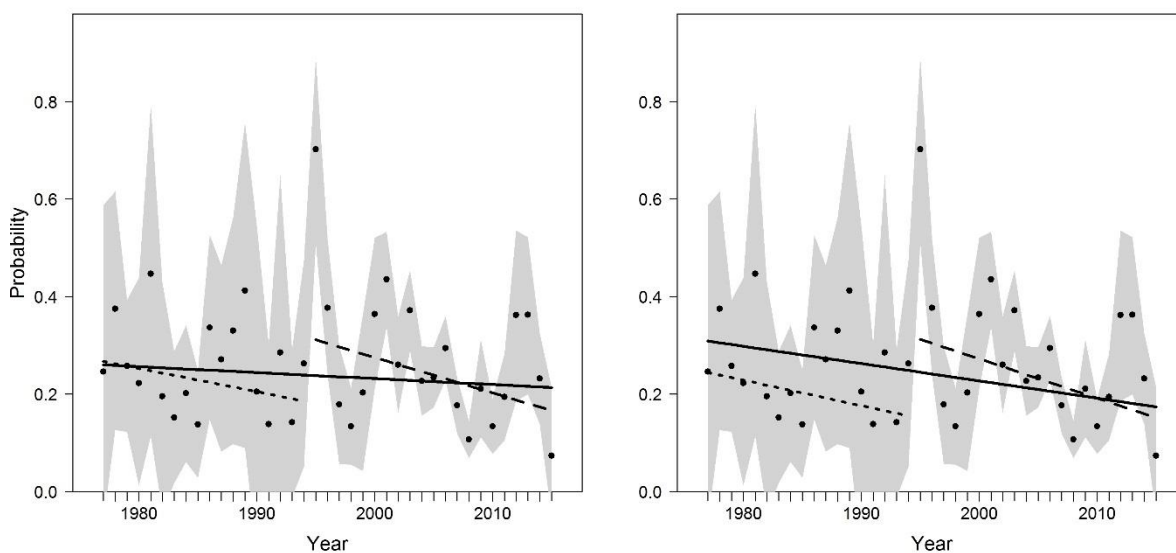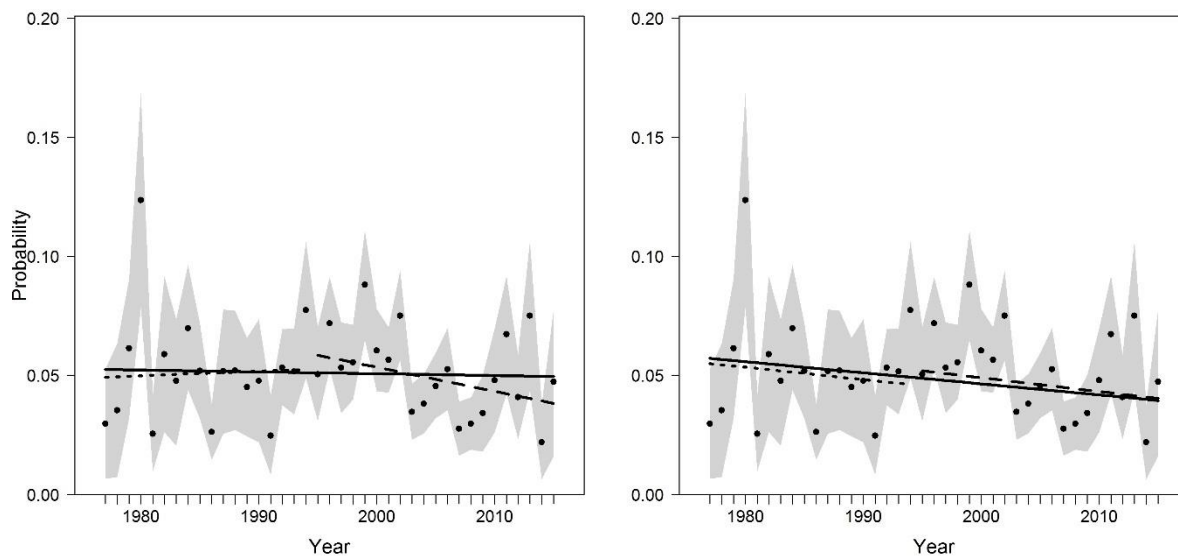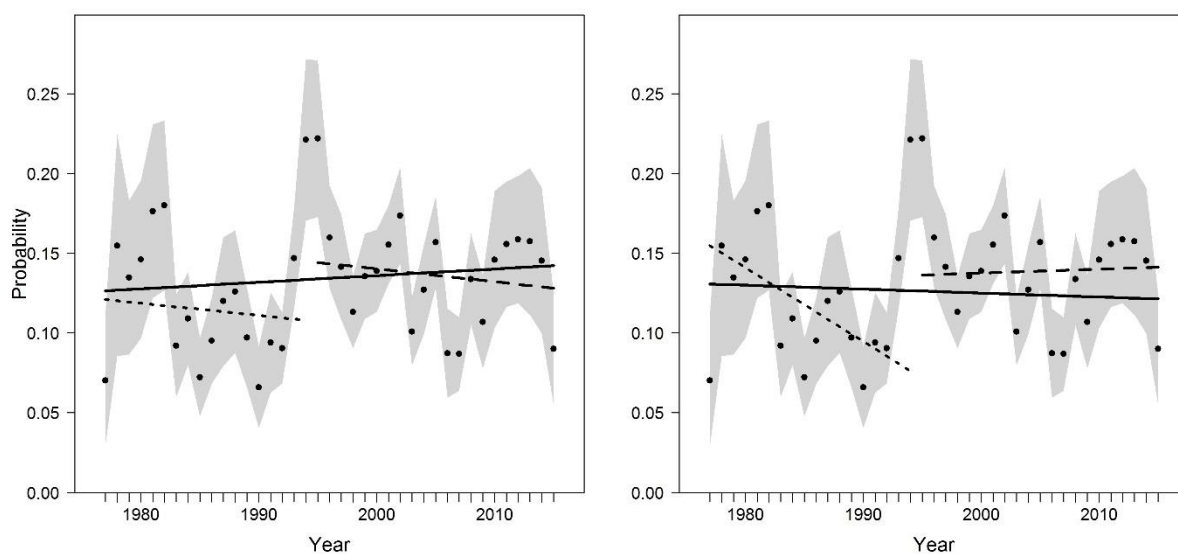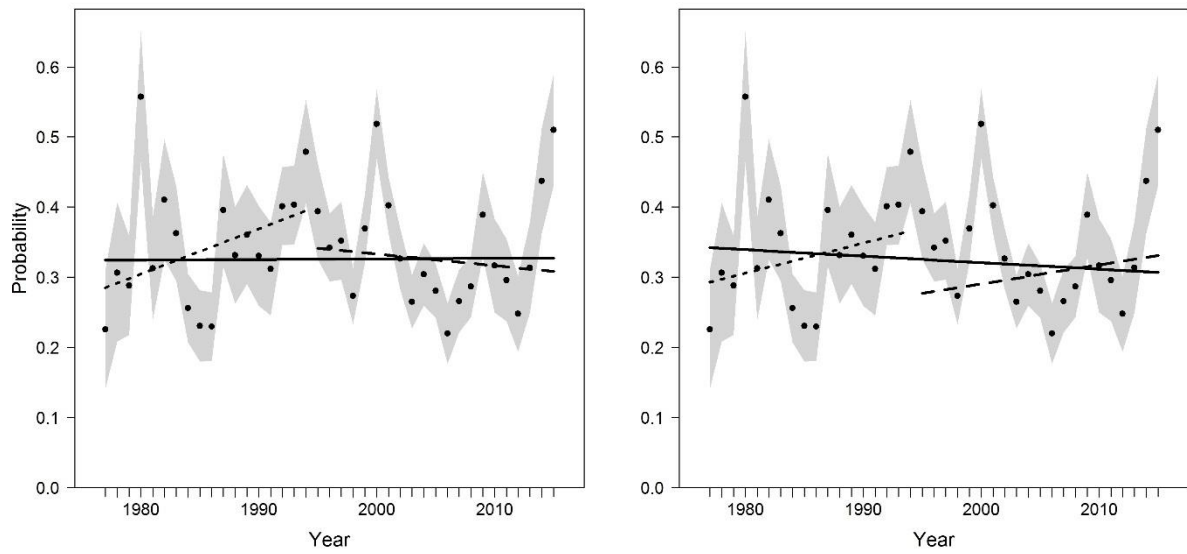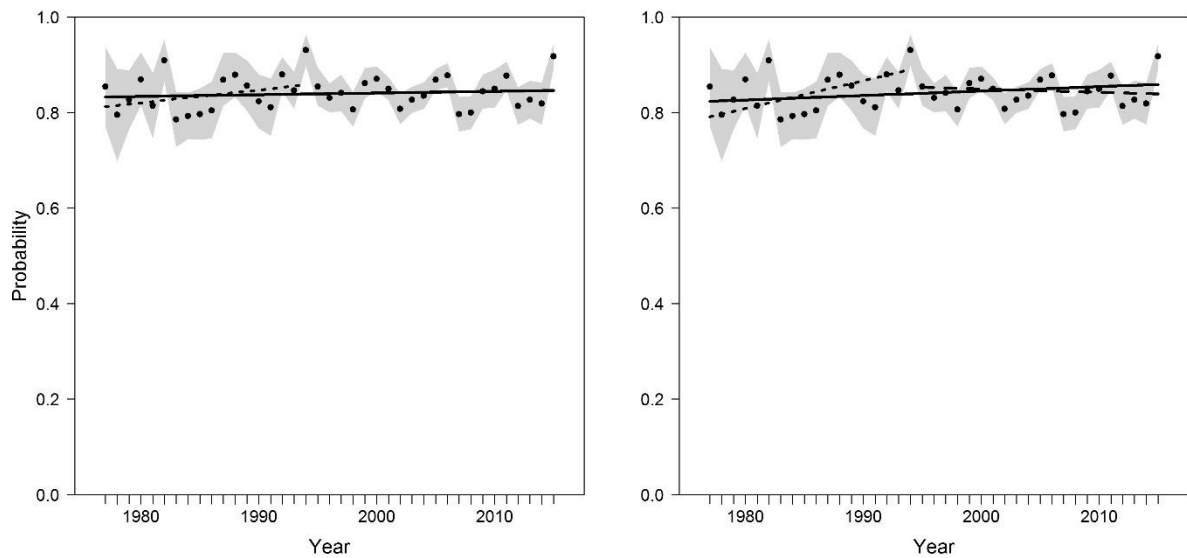

Canterbury galaxias Sen slope results for 1977–2015 (solid black line), 1977–1994 (dotted black line) and 1995–2015 (dashed black line). SSE results are shown on the left, while WSSE results are shown on the right.
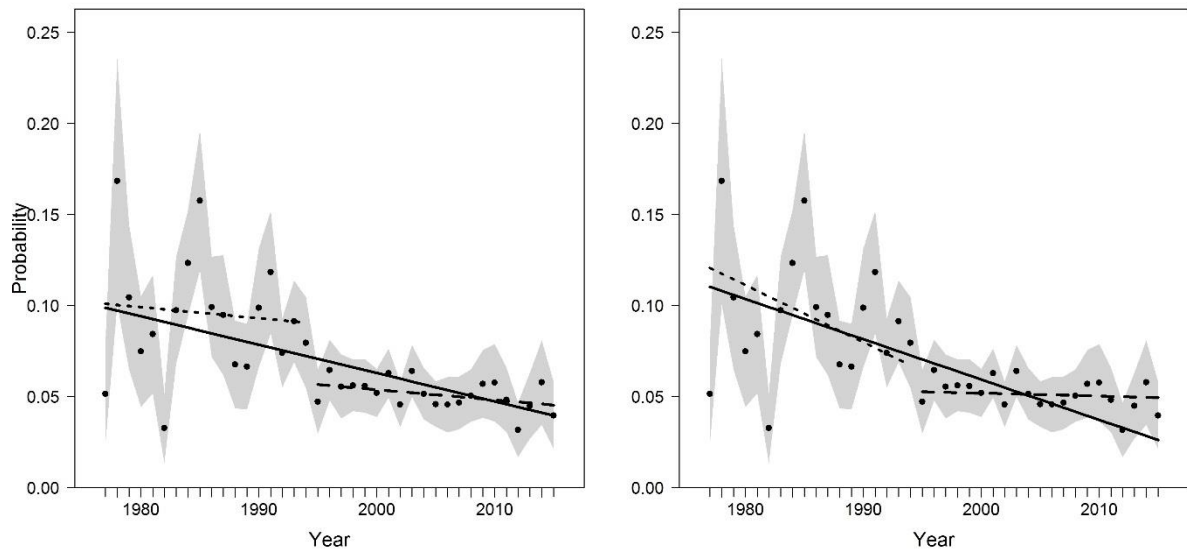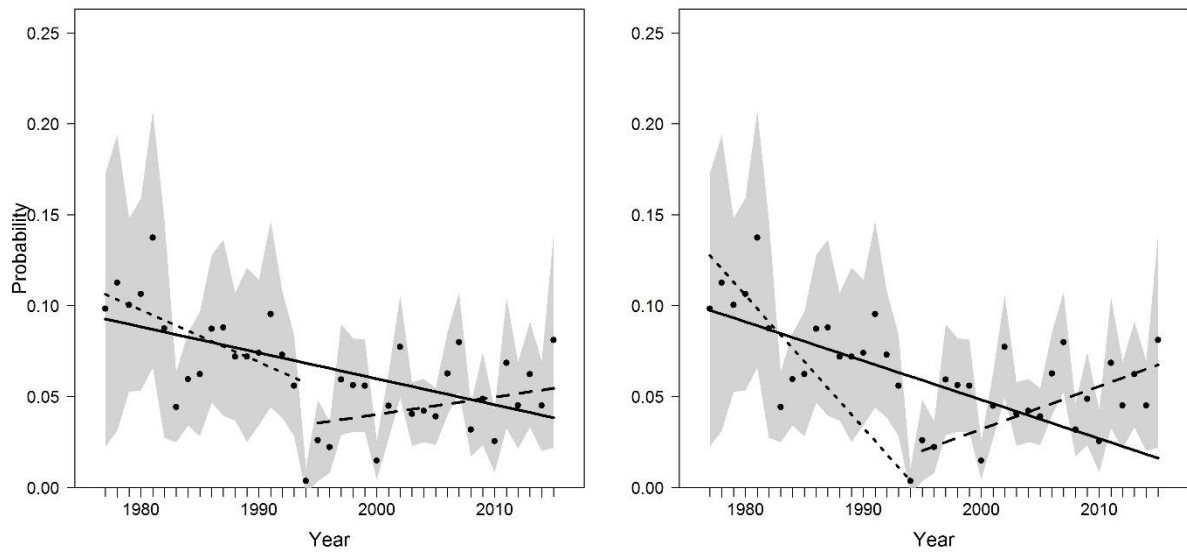
Common bully Sen slope results for 1977–2015 (solid black line), 1977–1994 (dotted black line) and 1995–2015 (dashed black line). SSE results are shown on the left, while WSSE results are shown on the right.
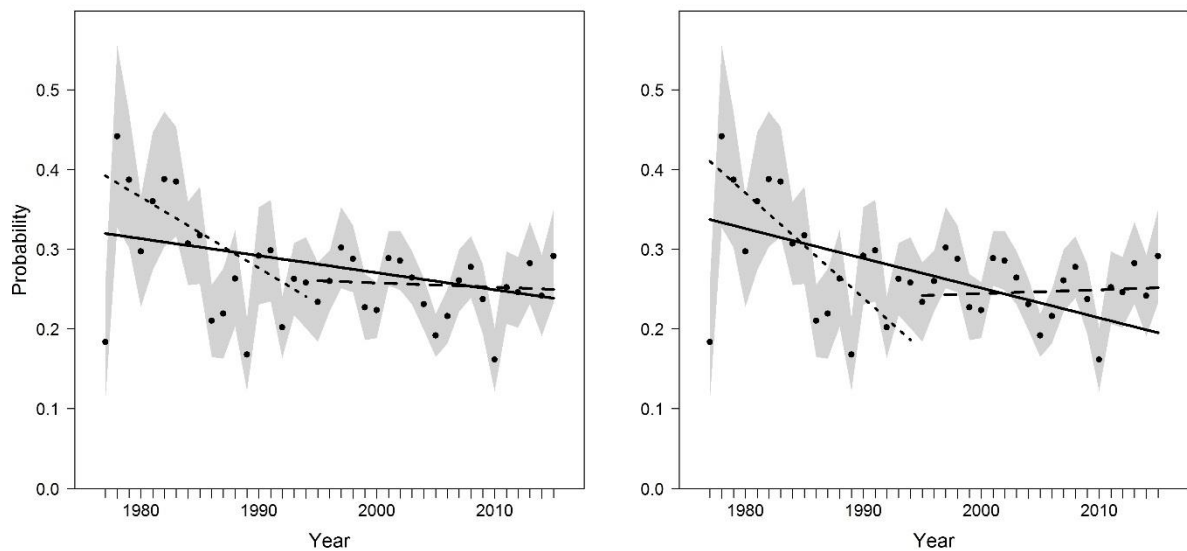
Exotic fish Sen slope results for 1977–2015 (solid black line), 1977–1994 (dotted black line) and 1995–2015 (dashed black line). SSE results are shown on the left, while WSSE results are shown on the right.
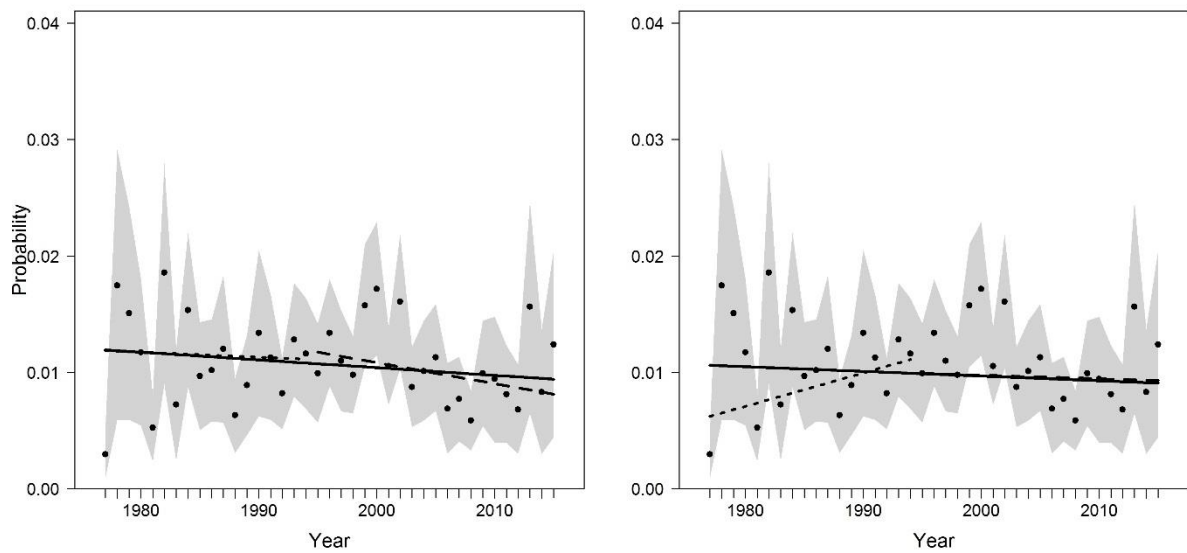
Kōaro Sen slope results for 1977–2015 (solid black line), 1977–1994 (dotted black line) and 1995–2015 (dashed black line). SSE results are shown on the left, while WSSE results are shown on the right.
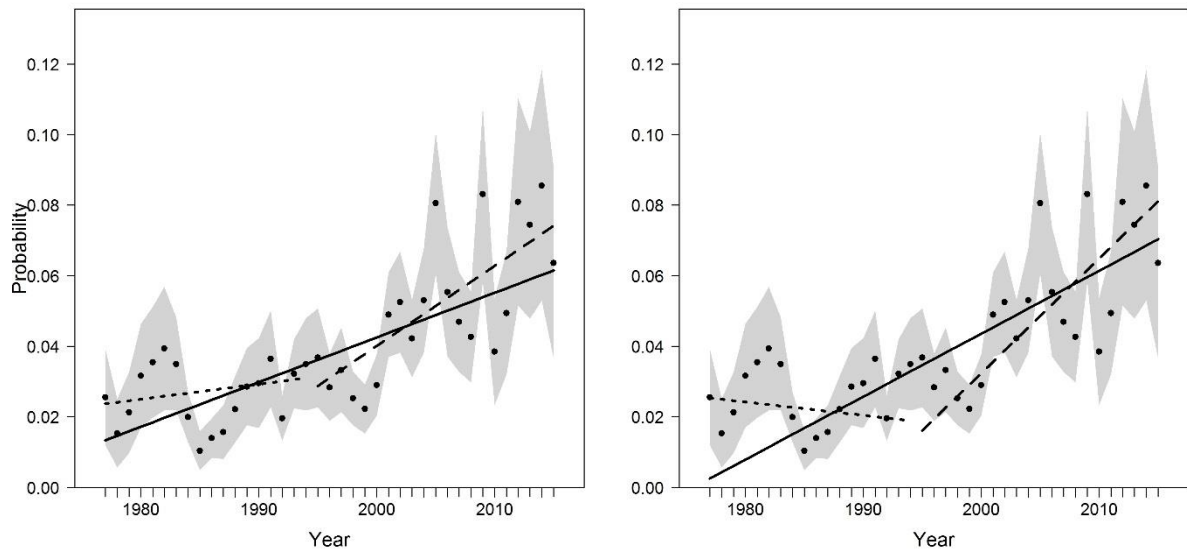

Kōura Sen slope results for 1977–2015 (solid black line), 1977–1994 (dotted black line) and 1995–2015 (dashed black line). SSE results are shown on the left, while WSSE results are shown on the right.

Longfin eel Sen slope results for 1977–2015 (solid black line), 1977–1994 (dotted black line) and 1995–2015 (dashed black line). SSE results are shown on the left, while WSSE results are shown on the right.
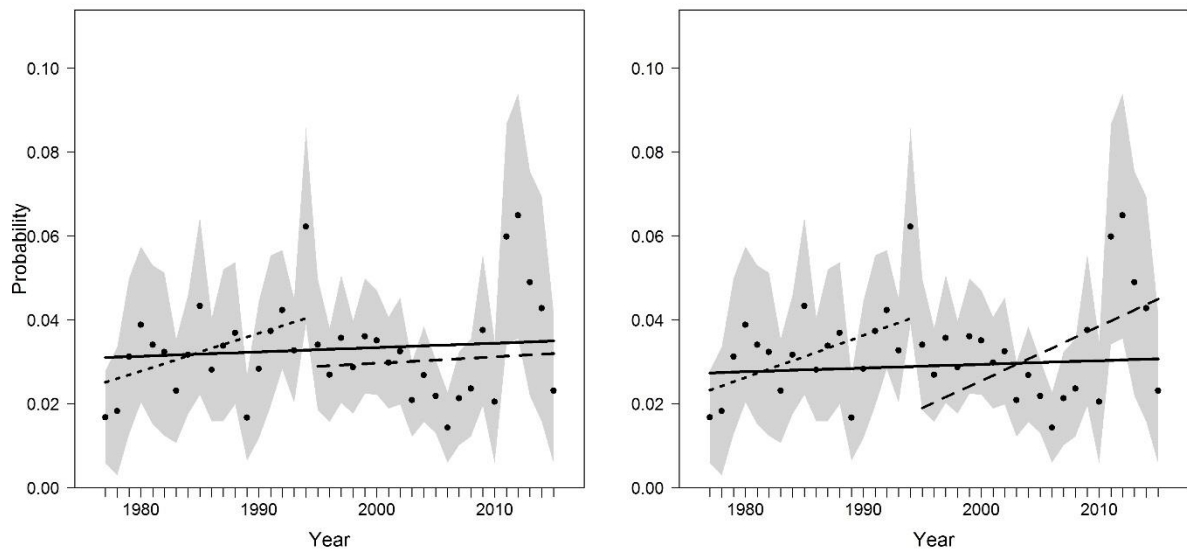

Native fish Sen slope results for 1977–2015 (solid black line), 1977–1994 (dotted black line) and 1995–2015 (dashed black line). SSE results are shown on the left, while WSSE results are shown on the right.

Rainbow trout Sen slope results for 1977–2015 (solid black line), 1977–1994 (dotted black line) and 1995–2015 (dashed black line). SSE results are shown on the left, while WSSE results are shown on the right.
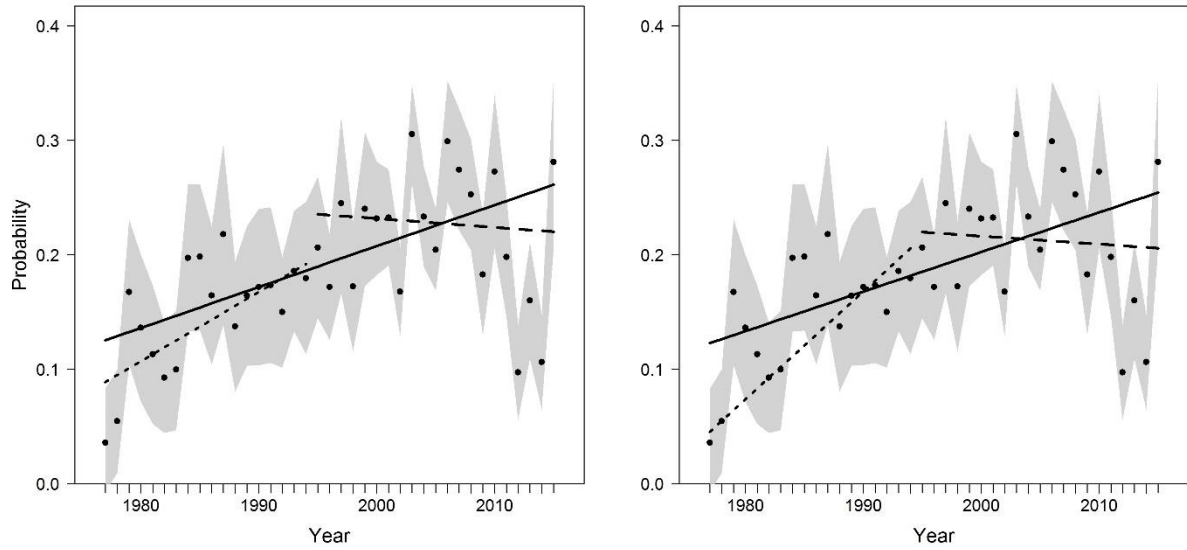

Redfin bully Sen slope results for 1977–2015 (solid black line), 1977–1994 (dotted black line) and 1995–2015 (dashed black line). SSE results are shown on the left, while WSSE results are shown on the right.

Shortfin eel Sen slope results for 1977–2015 (solid black line), 1977–1994 (dotted black line) and 1995–2015 (dashed black line). SSE results are shown on the left, while WSSE results are shown on the right.

Torrentfish Sen slope results for 1977–2015 (solid black line), 1977–1994 (dotted black line) and 1995–2015 (dashed black line). SSE results are shown on the left, while WSSE results are shown on the right.

Upland bully Sen slope results for 1977–2015 (solid black line), 1977–1994 (dotted black line) and 1995–2015 (dashed black line). SSE results are shown on the left, while WSSE results are shown on the right.