National Program for Sustainable Irrigation

Ecological Risk Associated with Irrigation in the Goulburn-Broken Catchment – Phase 2

Adverse changes to the abundance and diversity of native fish

MILESTONE 5: Fish Component

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Abstract
When assessing the ecological risks of irrigation activities in the Goulburn Broken Catchment, the problem formulation phase identified reduced native fish abundance and diversity as a priority issue. This report is a detailed investigation of native fish abundance and diversity in the catchment, identifying the current knowledge of the status of native fish communities in the catchment, identifying priority stressors to fish, and constructing a predictive model that can be used to inform how future decisions in the catchment will impact the native fishery.

The lowland Goulburn Broken Catchment has a long history of irrigation and has been highly modified primarily for the purpose of irrigation. Multiple barriers have been inserted in rivers and streams that have altered the hydrology of the system, and, in some cases, the water quality of the system. Barriers have also prevented the movement of native fish. Irrigation and urban run-off has further reduced water quality in the lower part of the catchment, contributing to increased turbidity and nutrient concentrations. Physical changes to the habitat of fish have also occurred as a result of extensive desnagging, removal of native riparian vegetation, and loss of complexity to river and stream geomorphology. Biological interactions have been altered due to the introduction of recreational salmonids, the proliferation of habitat generalists and changes to recruitment success of native fish. These changes have occurred both in the main channel and tributaries of the catchment.

The first task of this study was to identify and aggregate Goulburn Broken Catchment fisheries data from multiple sources, and investigate whether different fish communities exist in different parts of the catchment. Multivariate statistics were used and analyses showed that clearly the fish communities were fragmented. For the purpose of this study only, upper refers to the region below Eildon Dam, through to upstream of Lake Nagambie. The lower section refers to below Goulburn Weir, through to the confluence with the Murray River. Different communities existed in the upper tributaries and upper main channel, Lake Nagambie/Goulburn Weir, and in the lower tributaries and lower main channel. The findings of this component of the study identified barriers to migration, temperature changes and the altered flow regime as being the priority risks to fish in the catchment. Further analyses investigating the risks to fish were undertaken using the predictive Bayesian network (BN) model.

BNs are graphical models that maintain clarity by making causal relationships explicit and facilitating probability calculations. Basically, BNs can be described as probability networks that are updated using Bayes' theorem. The BN model endpoints developed in this study are native fish abundance and diversity. Given that the network has the ability to incorporate information with high uncertainty, it has the potential to support catchment management decisions regarding native

fish. Using the BN, scenarios for optimal management of fish populations at different sites and reaches within the catchment can be determined. The model has the ability to consider two temporal periods, 1 year and 5 years.

The BN model can be used to test alternative options for management of native fish in the catchment by entering interventions into the network and examining the relative change in the predictive probability endpoint distributions. The likely changes as a result of alternative scenarios tested are used to convey the expected system response while accounting for predictive uncertainties

The model construction process involved extensive liaison with expert stakeholders, both in the building of the model structure (qualitative component) and input of model relationships between model variables (quantitative component). Expert elicitation was conducted over two workshops. After the workshop examining the quantitative component of the model, the model performance post-workshop 2 was poor. Subsequently a greater commitment of time was invested in improving the quantitative component and reducing uncertainty of the model using data learning techniques. The model final product demonstrates that this process was worthwhile.

Using expert probabilities as prior estimations of variable quantitative relationships in the model, the data was used to update model probabilities. By examining the changes in expert probabilities as a result of automated data learning, the robustness of the expert elicitation process was tested. The final model incorporates quantitative relationships developed using both expert opinion and monitoring data. The monitoring data incorporated into the model originates from multiple monitoring programs currently being undertaken in the catchment.

Development of the BN was undertaken in collaboration with the Department of Computer Science and Software Engineering (CSSE) at Monash University. In collaboration with CSSE, tools for sensitivity analysis were developed to test the robustness of the model qualitative and quantitative components. These tools can also be used to identify variables of importance. Subsequently, the risk factors to fish can be ranked in order of importance. This process also identifies where further studies are required to improve the knowledge gaps in the model. Given that the BN model produced in this study is site specific, priority risks to fish differ according to the environmental condition of a particular area.

Predictive accuracy tests were also conducted on the model. Tests indicate that the accuracy of the model is high; however, given the absence of variability in many of the catchment variables contained within the model, testing the model performance over the full range of parameters cannot be done. At present the model has little experience in understanding the environmental conditions required for obtaining ‘healthy’ native fish populations, and model relationships are reliant on expert opinion. When charting the predicted model endpoints under existing environmental condition against current fishery data, the model outputs showed similar trends to the real data. In the tributaries, where fishery data is sparse, the model did not precisely identify all trends. To improve the accuracy of the model prediction for these areas, further data is required.

In the field of ecological risk assessment, there is increasing demand for ecological models that consider multiple stressors, incorporate data with high uncertainty, and integrate scientific information gained from multiple sources into a single predictive framework. Unlike mechanistic and simulation models, which suffer from problems integrating parameters measured at multiple scales and/or include irrelevant detail in attempt to improve predictions, BNs are able to represent information from multiple scales and still account for uncertainties. The variability in causal models is represented explicitly in probabilistic distributions. The process of constructing a BN is iterative, with new data and information being incorporated as it becomes available. This iterative process is well associated with the cyclic nature advocated as part of the ecological risk assessment paradigm, and extends the life span of models used in risk management.

The Bayesian network process and product is ideal for use in an adaptive management framework, and for encouraging stakeholder involvement. The concept is not too difficult to grasp, the product can be used to identify; what further information is required at the ecological risk assessment analysis stage and the model can be easily updated.

In summary, the native fish Bayesian network will inform:

1. How probable is an outcome (fish abundance and fish diversity) given existing environmental conditions?
2. What are the priority risks to fish in a given area?
3. How would outcomes be altered given a change in environmental condition (eg. projected increase in salinity)?
4. How would outcomes change given an external intervention (eg. management action)?
5. How would the priority risks to fish change following an external intervention?
6. What further data is needed to fill knowledge gaps within the model?

Knowledge of Risk Factors

The following sections are abstracted from the Pollino, Feehan, Grace and Hart paper submitted to *Marine and Freshwater Research*. The full paper is in Appendix 1.

<u>Study System</u>

The largest Victorian tributary of the Murray-Darling river system is the Goulburn River (Figure 1). The lowland portion of the Goulburn River has a long history of river regulation, primarily for the purpose of irrigation. The headwaters of the Goulburn River were first dammed in 1921 by Sugarloaf Dam (capacity of 377,400 ML). In 1955 this was replaced by the larger Eildon Dam (capacity of 3,390,100 ML), forming Lake Eildon. Water released from Lake Eildon is delivered 218 km downstream to the major offtake, Goulburn Weir (capacity of 25,000 ML) (Finlayson *et al.* 1994). Goulburn Weir was constructed in 1889 forming Lake Nagambie. From Goulburn Weir, outflows are to the lower Goulburn River and to irrigation areas via three large channels (Cottingham *et al.* 2003).

Multiple tributaries enter the 436 km lowland stretch of the Goulburn River, extending from Eildon Dam to its confluence with the Murray River (Gippel and Finlayson 1993). The majority of these tributaries have some form of barrier that can be inundated during higher flows in a typical year (DSE 2002). Barriers can include small farm dams, culverts, or other structures that may prevent migration of fish.

As a result of regulation, the hydrological regime of the lowland Goulburn River has been dramatically altered. Flow regulation has changed the hydrology of rivers at three scales: the flood pulse extending from days to weeks; flow history extending from weeks to years; and flow regimes extending decades or longer (Walker *et al.* 1995). Below Eildon Dam, the mean annual flow in the Goulburn River has not changed (Nathan 1992) but the mean monthly flows have been altered substantially with peak flows now occurring during summer/autumn rather than winter/spring (Gippel *et al.* 1993) (Figure 2). Flow maximums have also been reduced, resulting in fewer overbank flows and flooding of wetlands (Gippel *et al.* 1993); (Finlayson *et al.* 1994); (Ladson and Finlayson 2002). Finlayson *et al.* (1994) reported that wetlands that once flooded annually now only flood three years in ten. Hydrological changes decline downstream, with little post-dam change 200 km downstream as a result of flood runoff from tributaries (Erskine 1996). For charts showing monthly and seasonal pre- and post-river regulation average, maximum and minimum flows at Eildon and Murchson, refer to Appendix 2.

At Lake Nagambie/Goulburn Weir (Figure 1), water extraction has reduced the mean annual flow to the remaining section of the Goulburn River (Nathan 1992) but the natural seasonal flow pattern has been maintained. In the majority of tributaries, the hydrological regime remains largely intact.

In addition to changes in hydrology, Lake Eildon has had a major effect on water quality, primarily as a result of alterations in water temperature downstream of the dam structure. Lake Eildon is thermally stratified during summer and as water is released from below the thermocline, at a depth of 52 m below full supply level, water temperatures are lower than would naturally occur (Erskine 1996). As no pre-dam water quality exists, Gippel *et al.* (1993) modelled temperature parameters, assuming no dam. Model data demonstrates that water temperatures below Eildon Dam have been reduced by up to 7 degrees from natural in summer (Figure 3a). Altered thermal conditions extend 138 km downstream to Seymour (Gippel *et al.* 1993).

Only minor changes in dissolved oxygen were calculated, despite water released from Lake Eildon originating from deep within the reservoir (Figure 3b) (Gippel *et al.* 1993). In the lower sections of the Goulburn River, water quality is reduced due to increased turbidity, particularly downstream of the Broken River confluence, just upstream of Shepparton (Gippel *et al.* 1993). These high sediment loads in the lowermost portions of the river have resulted in some habitat simplification (Gippel *et al.* 1993). Nutrient concentrations are also increased in the lower catchment as a result of urban sources and intensive agriculture (State of Victoria 1989). In the tributaries of the catchment, water quality varies, with high turbidity and nutrients affecting certain areas.

Dams and other barriers have played a major role in reducing the distribution and diversity of fish in Australia (Cadwaller 1978; Gehrke and Harris 2001; Gehrke *et al.* 2002). Irrigation activities in the Goulburn Catchment have been implicated in causing a decline in the range and abundance of native fish (Cadwaller 1978). Changes in flow and thermal regimes have a marked effect on native fish, many of which require specific minimum water temperatures and flows for reproductive processes (Cadwaller 1978). Cadwaller (1978) hypothesised that as a result of regulation of rivers, the trigger mechanisms for spawning and recruitment have been removed, and the prevention of migration by barriers has lead to local extinctions. Fishways and fish ladders allow for movement of fish upstream, but there are no such fishways located on the Goulburn River, and only few fishways in tributaries.

Much of the riparian vegetation and woody debris along the Goulburn main channel and tributaries has been removed or is dominated by willows, an introduced plant species. Riparian vegetation is important for hindering predation of biota, and reducing sunlight and wind action, and minimising variations in water temperature (Barrella and Petrere 2003; Erskine and Webb 2003). Riparian vegetation also has an important role in acting as a source for woody debris, which forms an important component of fish habitat, provides spawning sites and can prevent over exploitation of biota (Koehn and O'Connor 1990).

Aside from the physical changes in the Goulburn as a result of river regulation, introduction of alien species has also been hypothesised as contributing to the decline in native fish (DNRE 2000a). Fish of the family Salmonidae were introduced in Australia in the late 1800's as a recreational species (Arthington and McKenzie 1997). Brown trout (*Salmo trutta*), rainbow trout (*Oncorhynchus mykiss*), and Atlantic salmon (*Salmo salar*) are still stocked at sites above Lake Nagambie/Goulburn Weir, and the Acheron River is considered to have a self-sustaining brown trout population (DNRE 2000a). Introduced salmonids are able to survive downstream of Eildon Dam throughout the year due to the altered thermal regime (Cadwaller 1978). Multiple other alien species are now established throughout the Goulburn River and tributaries, including common carp (*Cyprinus carpio*), goldfish (*Carassius auratus*), Gambusia (*Gambusia holbrooki*) and redfin perch (*Perca fluviatilis*). These species are considered habitat generalists, and are known to thrive in disturbed habitats (Stanford *et al.* 1966), often replacing the lost native fauna.

Although studies have concluded that environmental conditions in the Goulburn Catchment are detrimental to native fish (Gippel *et al.* 1993; Erskine 1996), conclusions have been based on changes to non-biological parameters.

Data aggregation and description

Despite the long history of irrigation in the Goulburn Broken Catchment and the documented decline in native fish, a thorough assembly and analysis of fisheries had not been conducted. The first step of this study was to aggregate fisheries data from multiple sources, organise it into a useable database, and use multivariate statistics to describe the current fishery. This database was also used for the BN model development described in the latter part of this report. The sites of interest are detailed in Table 1 and shown in Figure 1.

Study Methods

Description of Sites

The 4 sites selected for analysis in the upper region of the lowland main channel of the Goulburn River were Eildon (GEi), Alexandra (GA), Yea (GY) and Trawool (GT). The 8 upper tributaries were the Rubicon (R), Taggerty (T), Acheron (A), Murrindindi (M) and Yea Rivers (Y), and King Parrot (K), Sunday (Su) and Hughes (H) Creeks. The usage of the term 'upper' for these sites is relevant to this study only.

Lake Nagambie/Goulburn Weir (GN) is the only site representing the mid section of the Goulburn River main channel. The lentic environmental characteristics of Lake Nagambie/Goulburn Weir are distinct from that of the lotic environments of the Goulburn main channel and its tributaries.

The 6 main channel sites selected below the Goulburn Weir were Murchison (GMu), Shepparton (GS), Undera (GU), McCoy's Bridge (GMc) and at the confluence with the Murray River at Echuca (GE). Only 3 tributaries, Pranjip Creek (P), Castle Creek (C) and Seven's Creeks (Se), were suitable for analysis in the lower region. Overall, there are fewer tributaries in the lower Goulburn, compared to the upper (Figure 1). The majority of these sites selected are monitored for flow and/or water quality and have designated site numbers (Table 1).

A survey of environmental condition under the 'Index for Stream Condition' initiative rated sites in the Goulburn Catchment (Table 1). The survey assessed environmental condition based on changes to hydrology, physical form, streamside zone, water quality and aquatic life (macroinvertebrates only) indices (DSE 2002). The last survey was conducted in 1999. Sites along the Goulburn main channel were assessed as being between marginal and poor (Table 1).

Description of Data

Fisheries data were supplied by two agencies: the Department of Sustainability and Environment (DSE) and Department of Primary Industries (DPI). The Lake Nagambie Angling Club supplied additional data for Lake Nagambie. Only data post 1970 data was used in analyses.

Survey data consisted of site name and location, collection method and the species and number present. Fish were collected using a combination of techniques, including electrofishing, fyke nets, piscicide, fish traps and angling. In some cases, sample methods were not defined. Stocking data was not used in analyses as the success of stocking programs is unknown. In figures and tables denoting areas where stocking takes place, 'a' indicates stocking of non-native salmonids, and 'n' indicates stocking of natives. All native species of stocked fish are migratory species of commercial importance.

Native fish data were divided into migratory patterns, according to the classification used in (Thorncroft and Harris 2000) (Table 2). Species that undertake only local migrations are designated non-migratory throughout the paper. The majority of migratory fish in the Goulburn Catchment are classified as potamodromous (migrating within streams). The short-fin eel (*Anguilla australis*) is catadromous, migrating from freshwater to the sea to spawn. It is recognised that not all populations of migratory species follow these patterns in all areas, but categories are based on current scientific knowledge.

Collection of fishery data was not consistent at any site or between sites, and therefore no temporal analyses are conducted in this study. Data at each site was transformed according to the number of sampling dates. Fish assemblages constructed using the transformed data (Table 3). Data was transformed to ensure it was not skewed towards sites sampled more frequently.

Data interpretation

Species and abundance data were combined according to site location. Diversity at each of the sites was calculated using the Shannon Entropy (Shannon's H') (Shannon and Weaver 1949). The fish community variables, total fish abundance, number of species, and Shannon's H' at each of the sites were calculated, and differences between regions and stream types were measured by analysis of variance (ANOVA) (Gehrke *et al.* 2001). River region and main/tributary were used as factors in the analysis. Analyses were carried out using total abundance, native and alien abundance, and native non-migratory and native migratory species abundances. Abundance and diversity data were transformed using log (x + 1) to stabilise variances (Zar 1999). Tukey's honest significant difference test was used to determine significance between samples ($p \leq 0.05$) (Zar 1999). Analyses were performed using Statistica 5.1 (Statsoft, USA). The results of the Lake Nagambie dataset were excluded from ANOVA comparisons, as the dataset was not divided into multiple sites. The designation of multiple sites was not possible due to sampling grid references not always being available.

All remaining analyses were conducted using PRIMER 5.0 (Plymouth Marine Laboratory). Multi-dimensional scaling (MDS) ordinations were used to view sites in two dimensions. River region and site type (main/tributary) were used as factors in the analysis. Similarities between sites were calculated using the Bray-Curtis similarity measure (Bray and Curtis 1957). Data were transformed using log (x + 1) to reduce the influence of species with high abundances. Ordination was conducted on the calculated similarities among sites and used to examine relationships between sites and assess the influence of environmental condition on assemblages. Classifications used the group-average linking algorithm.

Analysis of similarities (ANOSIM) was calculated using the Bray-Curtis similarities (Clarke 1993). This was used to identify the differences between fish communities at each of the site groups. An ANOSIM is a non-parametric permutation procedure applied to the rank similarity matrix generated from the Bray-Curtis similarity measure (Clarke and Warwick 1994) and is analogous to an ANOVA comparing between group and within group variation (Quinn and Keough 2002). Up to 999 random permutations were used to estimate the probability of observed results.

Similarity Percentage (SIMPER) analysis was used to establish which species contribute to observed differences in the data. Species were ranked by examining the degree to which species contribute to measures of similarity/dissimilarity between site groupings (Clarke *et al.* 1994).

Study Results

Throughout the Goulburn Catchment, the Department of Primary Industries (DPI) undertakes a fish-stocking program (see Table 1 for locations). In the upper part of the main channel, recorded releases of brown trout (*Salmo trutta*) and rainbow trout (*Oncorhychus mykiss*) occur each year. As the upper Goulburn Catchment datasets contain Atlantic salmon (*Salmo salar*) counts, unrecorded releases must also have occurred, or fish may have escaped from local fish farms. Native fish stocking programs in the catchment release Macquarie perch (*Macquaria australasica*), golden perch (*Macquaria ambigua*), Murray cod (*Maccullochella peeli*), and trout cod (*Maccullochella macquariensis*).

Barred galaxias (*Galaxias fuscus*), trout cod and Macquarie perch are native to the catchment, and are classified as endangered under the *Environmental Protection and Biodiversity Conservation Act*

1999. Silver perch (*Bidyanus bidyanus*), flat-headed galaxias (*Galaxias rostratus*), mountain galaxias (*Galaxias olidus*) freshwater catfish (*Tandanus tandanus*), Murray cod (*Maccullochella peeli*), river blackfish (*Gadopsis mamoratus*), and rainbowfish (*Melanotaenia fluviatilis*) are listed as threatened fauna in Victoria (DNRE 2000b).

Community variables

A total of 29 fish species occur in the Goulburn River and tributaries. Nineteen species are native to the area, 9 of which have migratory patterns (Table 2). The remainder are alien fish from outside Australia. Native fish make up 47 percent of the dataset, with 11 percent of these undergoing some migration in their life history. The alien species, brown trout (*Salmo trutta*), Gambusia (*Gambusia holbrooki*), and goldfish (*Carassius auratus*), were clearly the most abundant species in the dataset (Table 3). The most abundant native species were river blackfish, barred galaxias and Australian smelt (*Retropinna semoni*).

Although ANOVA comparisons have limited applicability given the multiple sampling collection methods used, the results clearly show that there were no significant differences in total abundances of fish in the upper or lower regions or site types within the catchment (Table 4). Comparisons of native fish and alien fish abundances in each of the regions showed native fish abundances were significantly lower in the upper main channel sites, compared to all other sites (Table 4). Native fish abundances were particularly low at the Goulburn at Eildon site and Goulburn at Alexandra site (Figure 4A). Comparisons between native fish with different migratory patterns show that the abundance of non-migratory species at the lower main channel was significantly different to both upper Goulburn regions of the catchment. Native fish abundance made up 2 percent of fish abundance in the upper main channel, only 0.2 percent of these native fish had a migratory life history pattern. In the lower main channel native fish made up 42 percent of fish abundance, 9 percent of these native fish had a migratory life history pattern.

Alien species dominated the Goulburn main channel in both the upper and lower portions of the catchment. In the upper main channel, brown trout and rainbow trout made up 53 and 31 percent of data respectively. In the lower main channel, common carp (*Cyprinus carpio*) and goldfish (*Carassius auratus*) made up 18 and 16 percent of abundance respectively.

Generally, the number of species and diversity increased with distance from Eildon Dam (Figure 4B & 4C). Comparisons between the numbers of species in each region showed there were significant differences (Table 4), with increasing numbers of species in the lower sections of the study area, compared to the upper (Figure 4B). There were no differences between site types. Analyses for all fish data, native fish data and non-migratory/migratory data had similar outcomes, with species numbers changing between regions, but not between site types (Table 4). Comparisons between total Shannon diversity (H') values of all fish again showed there were differences between regions but not site type (Figure 4C). However, both region and site type were significant for native fish diversity alone (Table 4). Results indicate there was reduced diversity in the upper region compared to the lower region (Table 4), and native fish diversity was different according to site type. The lower regions support multiple species of both non-migratory and migratory fish, unlike the upper section, which is composed mainly of alien non-migratory species.

Table 1: Site information and location of lowland river sites in the Goulburn Catchment ('a' denotes stocking of alien salmonids, and 'n' denotes stocking of natives).

Region	Type	Stream	Nearest town, landmark, roadway	Site no.	Site code	Latitude	Longitude	Stocking	ISC score
Upper	Main	Goulburn River	Eildon	405203	GEi	-37.250	145.870	a	Poor
		Goulburn River	Alexandra	-	GA	-37.170	145.510	a	Poor
		Goulburn River	Yea	-	GY	-37.184	145.369	-	Very Poor
		Goulburn River	Trawool	405201	GT	-37.090	145.200	-	Very Poor
Upper	Tributary	Rubicon River	Rubicon	405241	R	-37.290	145.820	a	-
		Taggerty River	Lady Talbot Dve	-	T	-37.290	145.510	a	Excellent
		Acheron River	Taggerty	405209	A	-37.320	145.710	a	Excellent
		Murrindindi River	Above Colwells	405209	M	-37.410	145.560	a	Marginal
		Yea River	Devlins Bridge	405217	Y	-37.380	145.470	an	Marginal
		King Parrot Creek	Flowerdale	405231	K	-37.350	145.290	a	Marginal
		Sunday Creek	Tallarook	405212	Su	-37.380	145.050	a	Marginal
		Hughes Creek	Tarcombe Rd	405228	H	-36.950	145.280	an	Marginal
Mid	Main	Lake Nagambie	Nagambie	-	GN	-36.470	145.800	an	-
Lower	Main	Goulburn River	Murchison	405200	GMu	-36.620	145.220	n	Poor
		Goulburn River	Shepparton	405200	GS	-36.380	145.390	n	Poor
		Goulburn River	McCoys Bridge	405232	GMc	-36.180	145.120	-	Poor
		Goulburn River	Undera	-	GU	-36.277	145.342	-	Poor
		Goulburn River	Echuca	-	GEc	-36.135	145.002	-	Poor
Lower	Tributary	Pranjip Creek	Moorilim	405226	P	-36.620	145.310	-	Marginal
		Castle Creek	Arcadia	405246	C	-36.590	145.350	-	Marginal
		Seven's Creek	Polly McQuinn Weir	405234	Se	-36.890	145.680	n	Marginal

Table 2: Native fish species (n) and alien species (a) found in the Goulburn Catchment.

Common Name	**Scientific Name**	**Migratory Pattern***	**n/a**
Atlantic salmon	*Salmo salar*	Local	a
Australian smelt	*Retrospinna semoni*	Potamodromous	n
Barred Galaxias	*Galaxias fuscus*	Local (?)	n
Bony bream	*Nematalosa erebi*	Potamodromous	n
Blackfish	*Gadopsis marmoratus*	Local	n
2-Spined blackfish	*Gadopsis bispinosus*	Local	n
Brown trout	*Salmo trutta*	Local	a
Carp	*Cyprinus carpio*	Local/Potamodromous	a
Catfish	*Tandanus tandanus*	Local	n
Goldfish	*Carassius auratus*	Local/Potamodromous	a
Golden Perch	*Macquaria ambigua*	Potamodromous	n
Flat-headed Galaxias	*Galaxias rostratus*	Local	n
Flat-headed Gudgeons	*Philyphodon grandiceps*	Local (?)	n
Hybrid carp	*Cyprinus carpio x Carassius auratus*	Local/Potamodromous	a
Macquarie Perch	*Macquaria australasica*	Potamodromous	n
Mirror carp	*Cyprinus carpio*	Local/Potamodromous	a
Mosquitofish	*Gambusia affinis / Gambusia holbrooki*	Local (?)	a
Mountain galaxiid	*Galaxias olidus*	Local	n
Murray cod	*Maccullochella peeli*	Potamodromous	n
Pygmy Perch	*Nannoperca australis*	Potamodromous (?)	n
Rainbowfish	*Melanotaenia fluviatilis*	Local	n
Rainbow trout	*Oncorhychus mykiss*	Local	a
Redfin	*Perca fluviatilis*	Potamodromous	a
Short-finned eel	*Anguilla australis*	Catadromous	n
Silver Perch	*Bidyanus bidyanus*	Potamodromous	n
Tench	*Tinca tinca*	Local (?)	a
Trout Cod	*Maccullochella macquariensis*	Potamodromous (?)	n
Western carp gudgeon	*Hyperseleotris klunzingeri*	Local	n

*Thorncraft & Harris (2000) Fish Passage and Fishways in New South Wales: A Status Report. Cooperative Research Centre for Freshwater Ecology Technical Report 1/2000.

Table 3: Summary of fish assemblages, using transformed abundances (see table 1 for definition of site symbols).

	GEi	**GA**	**GY**	**GT**	**R**	**T**	**A**	**Y**	**M**	**K**	**Su**	**H**	**GN**	**GMu**	**GS**	**GMc**	**GU**	**GEc**	**P**	**C**	**Se**
Hypseleotris klunzingeri	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.3	0.5	0.8	12	7.7	0.7
Hypseleotris	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.5	0.0	0.4	20	0.5	0.0	1.9	0.5	0.0
Philypnodon grandiceps	0.2	0.2	0.6	0.3	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.7	36	0.0	0.0	17	1.5	0.5	0.0	0.0	0.0
Galaxias rostratus	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.5	0.0	0.0	0.0	0.0	0.0
Galaxias fuscus	0.0	0.0	0.0	0.0	27	15	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Galaxias olidus	0.0	0.0	0.0	0.0	0.2	0.2	0.6	0.6	0.0	0.3	0.1	1.9	0.0	0.0	0.0	0.0	0.0	0.0	3.9	1.0	1.1
Gadopsis bispinosus	0.1	0.1	0.6	0.8	3.1	0.3	4.1	0.0	0.2	15	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Gadopsis mamoratus	0.0	0.0	0.0	0.0	0.2	0.0	0.0	3.8	0.2	0.4	12	24	0.8	0.3	0.0	0.0	0.0	0.0	2.8	0.0	26
Anguilla (sfin eel)	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Nannoperca australis	0.1	0.0	0.0	0.3	0.0	0.0	0.0	2.3	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	23	3.5	2.5
Macquaria australasica	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.0	0.1	0.0	4.2	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	12
Macquaria ambigua	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	2.0	0.6	0.3	0.5	0.3	0.0	0.0	0.2
Maccullochella macquariensis	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7	0.0	3.0	0.0	0.0	0.0	0.0	0.0	0.0	7.6
Maccullochella peeli	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.2	0.6	0.0	0.0	0.3	0.0	0.0	0.1
Melanotaenia fluviatilis	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7	0.5	23	0.5	0.3	0.0	0.0	0.0
Retropinna semoni	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	20	0.0	2.4	26	1.0	1.3	1.1	1.3	0.2
Nematalosa erebi	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0
Bidyanus bidyanus	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.0	0.0	0.0	0.3	0.0	0.0	0.1
Tandanus tandanus	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Mordacia mordax	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Gambusia holbrooki	0.0	0.1	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	2.7	0.0	5.1	56	0.5	0.8	0.4	8.3	0.0
Cyprinus carpio	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	17	1.3	2.9	14	1.0	0.8	5.3	0.2	2.2
Cyprinus auratus	0.0	0.1	0.0	0.3	0.2	0.0	0.0	0.4	0.0	0.0	0.1	0.2	4.6	0.3	1.0	52	1.5	1.0	0.9	0.0	0.2
Carassius x Cyprinus hybrid	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.0	0.0	0.3	0.4	0.0	0.0
Tinca tinca	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.4	0.1	0.2	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0
Perca fluviatilis	0.4	0.6	0.2	0.5	0.3	0.0	0.0	4.3	0.2	0.1	0.1	0.3	16	0.0	0.5	5.5	1.0	1.3	1.4	0.0	4.7
Oncorhynchus mykiss	8.5	2.8	8.0	3.8	2.3	10.6	0.6	0.0	0.3	0.2	0.0	0.0	0.1	0.3	0.0	0.0	0.0	0.0	0.0	0.0	2.5
Salmo trutta	51	31	35	8.8	23	1.1	4.2	7.0	0.3	2.6	3.3	0.3	0.2	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.1
Salmo salar	0.8	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Non-migratory	0.4	0.3	1.2	1.3	31	16	4.7	6.6	0.3	16	12	26	43	1.0	1.1	62	3.0	1.5	44	13	30
Migratory	0.1	0.2	0.0	0.0	0.0	0.0	0.0	0.5	0.0	0.2	0.0	5.1	20	5.8	3.8	27	1.5	2.0	1.1	1.3	20
Alien	61	35	43	14	26.0	12	4.8	12	0.8	2.9	7.0	0.9	42	2.3	9.5	133	4.0	4.0	8.4	8.5	9.8
Total	61	35	44	15	57	27	9.4	19	1.2	19	19	32	105	9.2	14	222	8.5	7.5	54	23	60

Table 4: Probability values obtained from analyses of variance of fish community variables, using waterway region and site type as factors.

	Abundance			No. of Species			Diversity	
Factors	**All**	**Native vs. Alien**	**Migratory vs. Non-migratory**	**All**	**Native vs. Alien**	**Migratory vs. Non-migratory**	**All**	**Natives**
Region[a] (1)	0.76	5×10^{-5}	0.04	0.05	0.003	0.01	1×10^{-6}	1×10^{-4}
Site type[b] (2)	0.96	3×10^{-5}	0.002	0.15	0.46	0.16	0.84	0.01
1 x 2	0.14	4×10^{-4}	0.14	0.56	0.27	0.21	0.004	0.33

[a] Upper or Lower
[b] Main or Tributary

Despite dams preventing migration, three species of migratory species were sampled above Goulburn Weir. The short-fin eel (*Anguilla australis*) was found at Eildon. This species is able to climb dam walls (Gehrke *et al.* 2002), and was possibly attempting to migrate further upstream. Australian smelt was present at both Alexandra and King Parrot Creek. This species is widespread throughout the catchment, is found in slow and fast flowing waters (Lake 1967), has a protracted spawning period (Humphries *et al.* 1999) and is not an obligate migratory species. The Macquarie Perch data from King Parrot Creek may represent previous, unrecorded stocking, or represent a remnant non-migratory population. The Department of Primary Industries conducts stocking of migratory species in Hughes Creek and Yea River, and migratory species data exists for both tributaries.

Results of analyses investigating native fish abundance and diversity at Lake Nagambie indicated that this site was comparable to the lower sites (Figure 4C). Native species were stocked in the lake prior to 1996 (DNRE 2000a) but anecdotal evidence suggests the fishery declined in the 1980's. Data from post-1990 show the loss of obligate native migratory species, and currently the flat-headed gudgeon (*Philypnodon grandiceps*) is the most abundant species in the lake, followed by Australian smelt.

Composition of fish communities

The classification of sites based on the similarities in species composition of the entire dataset showed separation between the uppermost and lowermost sections of the Goulburn main channel (Figure 5a). Lake Nagambie is placed among sites in the lower group. Both the MDS plot and cluster analysis show that the separation of the upper and lower main channel sites is clear; however, the separation of tributaries is not as defined, but are generally placed on opposing sides of the axis (Figures 5a and 5b). The ANOSIM results were significant for both region and site types and significant for all upper sites compared to lower sites (Table 5).

Using native fish data only, the MDS ordination site grouping was less defined (Figure 6a), although cluster analysis also showed clear separation of the upper and lower main channel sites (Figure 6b). ANOSIM results were still significant for both sites and regions and significant for all upper sites compared to lower sites (Table 5). Thus, the compositions of communities within the upper main channel were significantly different to those of the upper tributaries, and this relationship was also found for the main channel and tributaries in the lower region (Table 5).

Overall, the evidence for different species groups at each of the regions and site types was strong. Communities in each of the site types of the upper regions showed little consistency to those in the lower regions. Dominance of different species groups at each region and stream type was clear (Table 6). Dissimilarities between the regions and streams at the main channel sites were predominately due to the alien species. In the upper main channel reach, brown trout and rainbow trout dominated abundance, and in the lower main channel reaches, Gambusia, common carp and goldfish dominate. Dissimilarities between the upper and lower tributaries were due to a mixture of native and alien species. Brown trout, barred galaxias and blackfish dominated the upper tributaries (Table 6), and the lower tributaries had high abundances of blackfish, pygmy perch (*Nannoperca australis*), and carp gudgeon (*Hyperseleotris klunzingeri*). There were also high dissimilarities between the fish community in the mid region as compared to those in the upper regions (Table 6), despite the absence of a physical barrier separating the communities. Flat-headed gudgeon, Australian smelt and common carp were found in highest abundance in the mid region.

Table 5: Summary of ANOSIM results using waterway region and site type as factors.

Data	Source	R-value	Probability
All	Differences between regions	0.778	0.001
	Differences between site type	0.248	0.015
	Pairwise tests:		
	Upper Main vs. Upper Trib	0.088	0.240
	Upper Main vs. Mid Main	1.000	0.200
	Upper Main vs. Lower Main	1.000	0.008
	Upper Main vs. Lower Trib	0.963	0.029
	Upper Trib vs. Mid Main	0.839	0.111
	Upper Trib vs. Lower Main	0.912	0.001
	Upper Trib vs. Lower Trib	0.608	0.006
	Mid Main vs. Lower Main	0.200	0.333
	Mid Main vs. Lower Trib	0.333	0.750
	Lower Main vs. Lower Trib	0.569	0.054
Natives	Differences between regions	0.477	0.001
	Differences between site type	0.510	0.001
	Pairwise tests:		
	Upper Main vs. Upper Trib	0.424	0.018
	Upper Main vs. Mid Main	0.833	0.200
	Upper Main vs. Lower Main	0.800	0.008
	Upper Main vs. Lower Trib	1.000	0.067
	Upper Trib vs. Mid Main	0.848	0.111
	Upper Trib vs. Lower Main	0.907	0.002
	Upper Trib vs. Lower Trib	0.355	0.048
	Mid Main vs. Lower Main	0.200	0.333
	Mid Main vs. Lower Trib	0.778	0.250
	Lower Main vs. Lower Trib	0.733	0.018

Table 6: Species contributing to the greatest differences between fish communities in select parts of the Goulburn Catchment.

Species	Mean Abundance		Ratio	Percent	Cumulative (%)
Upper Main & Lower Main: mean dissimilarity = 95.47					
Salmo trutta	31.3	0.07	6.92	40.0	39.95
Oncorhynchus mykiss	5.74	0.07	2.30	8.15	48.10
Gambusia holbrooki	0.08	12.5	1.14	7.86	55.97
Cyprinus auratus	0.08	3.99	1.69	6.60	62.57
Cyprinus carpio	0.08	11.3	2.61	6.43	68.99
Upper Main & Lower Tributaries: mean dissimilarity = 86.89					
Salmo trutta	31.3	0.03	7.30	17.2	17.22
Hyperseleotris klunzingeri	0.01	6.67	1.75	10.0	27.25
Nannoperca australis	0.08	9.84	2.32	10.0	37.28
Oncorhynchus mykiss	5.74	0.84	2.31	8.95	46.23
Gadopsis mamoratus	0.00	9.47	1.15	7.07	53.29
Upper Trib & Lower Tributaries: mean dissimilarity = 78.56					
Salmo trutta	5.26	0.03	2.51	11.3	11.33
Hyperseleotris klunzingeri	0.00	6.77	1.83	10.5	21.80
Nannoperca australis	0.32	9.84	2.17	10.2	31.97
Gadopsis mamoratus	4.99	9.47	1.30	7.71	36.69
Gadopsis bispinopsis	2.81	0.01	0.99	7.14	46.83
Upper Tributaries & Lower Main: mean dissimilarity = 95.47					
Salmo trutta	5.26	0.07	1.44	12.0	11.97
Gadopsis mamoratus	4.99	0.08	0.78	11.2	23.14
Gadopsis bispinopsis	2.81	0.00	0.66	9.41	32.56
Gambusia holbrooki	0.01	12.5	1.16	7.99	40.55
Galaxias fuscus	5.25	0.00	0.57	6.74	47.29
Upper Main & Mid Main: mean dissimilarity = 95.90					
Salmo trutta	31.3	0.20	6.25	40.1	40.08
Philypnodon grandiceps	0.31	36.2	50.0	17.5	57.56
Retrospinna semoni	0.04	19.8	88.4	9.78	67.34
Cyprinus carpio	0.08	17.3	39.0	8.48	75.82
Oncorhynchus mykiss	5.74	0.01	2.18	8.45	84.27
Upper Tributaries & Mid Main: mean dissimilarity = 94.18					
Philypnodon grandiceps	0.31	36.2	43.8	18.1	18.14
Salmo trutta	5.26	0.20	1.38	12.3	30.49
Gadopsis mamoratus	4.99	0.80	0.73	11.3	41.76
Retropinna semoni	0.01	19.8	149	9.99	51.75
Gadopsis bispinopsis	2.81	0.00	0.62	9.54	61.29
Mid Main & Lower Tributaries: mean dissimilarity = 82.51					
Philypnodon grandiceps	36.2	0.00	14.9	14.3	14.34
Nannoperca australis	0.00	9.84	2.57	11.1	25.43
Hyperseleotris klunzingeri	0.00	6.77	1.56	10.6	35.59
Retrospinna semoni	19.8	0.87	2.47	7.44	43.03
Perca fluviatilis	16.6	2.04	1.39	6.89	49.92
Lower Main & Lower Tributaries: mean dissimilarity = 81.95					
Nannoperca australis	0.00	9.84	3.03	10.1	10.12
Cyprinus auratus	11.3	0.37	2.53	7.58	17.70
Hyperseleotris klunzingeri	0.32	677	1.53	7.05	24.75
Melanotaenia fluviatilis	5.13	0.00	4.22	6.98	31.72
Gambusia holbrooki	12.5	2.92	1.46	6.70	38.42

The only groups from different regions that are comparable were the mid region and the lower main channel (average dissimilarity = 43). Dissimilarities between tributaries and the main channel of the upper region were comparatively low (average dissimilarity = 69) compared to comparisons between tributaries and the main channel of the lower reach (average dissimilarity = 82). In the lower portion of the catchment, alien species dominate the main channel, and tributaries have a higher abundance of native fish.

Findings from Multivariate Analyses

Although total fish abundance at each of the portions of the catchment was similar, when comparing the abundance of native species and alien species independently, a considerable difference between abundance in the different parts of the catchment is evident. The higher abundance of non-migratory fish in the upper tributaries compared to the main channel, and increasing migratory fish abundance in the lower part of the catchment is clear. Likewise, species diversity in the Goulburn Catchment increased with distance from Eildon Dam, with greater numbers of migratory species downstream of Goulburn Weir. Below Goulburn Weir, and particularly at Murchison just below the weir structure, a pronounced increase in migratory species is evident.

The increasing abundance and diversity of native species downstream of Trawool indicates that conditions in the upper reaches of the catchment, especially in the main channel, create an unsuitable habitat for native fish, thus forming an artificial barrier to fish habitation and movement. Native fish community compositions at each of the site types were considerably different. It has been reported previously that spawning of native fish in the main channel above Lake Nagambie is unlikely due to the reduced water temperature as a result of hypolimnetic releases from Eildon Dam (Ladson *et al.* 2002). Fish survey data further confirmed this, with increased abundance of native fish in the tributaries of the upper reaches, compared to the main channel, where temperatures are unchanged.

Fish surveys in the regulated Shoalhaven River (NSW) also found migratory species have mostly disappeared above the Tallowa Dam structure (Gehrke *et al.* 2002). Unregulated inland rivers in south-eastern Australia traditionally exhibit a downstream reduction in diversity (Gehrke and Harris 2000). The Goulburn River, like other regulated rivers, has a downstream increase in diversity. The absence of migratory species above Goulburn Weir is a result of the weir acting as a physical barrier, preventing migration. As migration is an important component of reproductive behaviour for obligate migratory species (Reynolds 1983), the data in this study lends weight to the belief that self-sustaining populations of migratory fish are unlikely to be found in Lake Nagambie or the upper tributaries of the catchment.

As a result of the construction of Tallowa Dam, Gehrke *et al.* (2002) found localised extinctions have taken place, an artificial discontinuity divided fish communities, divergent populations of species lived upstream and downstream of the dam, there was an accumulation of species at the dam wall and non-native species have become established (Gehrke *et al.* 2002). Tallowa Dam has not altered the thermal regime in the Shoalhaven River system, as no hypolimnetic release occur from the lake. The results of (Gehrke *et al.* 2002) resemble those of the Goulburn River where it is clear the basic structure of the fish community in each part of the catchment is no longer intact.

Fish communities in each of the regions and site types of the Goulburn Catchment had distinctive community structures, being dominated by alien species in the main channels, and a combination of native and alien species in the tributaries. Fish communities in the main channel below the large deep release Eildon Dam were divergent from those where water temperatures are unchanged.

The effects of flow regulation on stream communities is often most severe below a dam, with effects becoming less severe as tributary inflow and other physical processes mitigate effects (Brown and Ford 2002). Distinctly different community compositions occur in the less regulated lower sections of the Goulburn River where seasonal flow patterns and thermal patterns are maintained, compared with the highly regulated upper sections where seasonal flows are reversed and water temperatures reduced.

As there is no pre-regulation fish data, the original community composition of the Goulburn Catchment is unknown; however, the absence of migratory species above Lake Nagambie, and the paucity of native fish in the upper main channel demonstrate a dramatic change in fish communities as a result of regulation. The pre-regulation conditions in the upper catchment would be suitable for spawning of select native species inhabiting the Goulburn Catchment. Murray cod, Macquarie perch and fish from the Galaxiidae and Gadopsidae families are known to spawn (Koehn *et al*. 1990) at the pre-regulation water temperatures modelled by Gippel *et al.* (1993). Their absence in tributaries suggests this probably results from the presence of artificial barriers, as a result of changes to water quality, and physical barriers to migration.

Eildon Dam has also had a dramatic effect on fish communities upstream of the structure (Cadwaller and Rogan 1977). The lake and feeder streams were once abundant with the obligate migratory species Macquarie Perch, but populations have declined to the point where the species have virtually disappeared and non-native species dominate abundance (Cadwaller *et al.* 1977). Despite there being no evidence of localised extinctions taking place below Eildon dam, it is likely that this has occurred.

Alien species clearly dominate throughout the Goulburn Catchment, whether the result of stocking, or due to fish flourishing in the altered conditions. Successful establishment of non-native forms varies, but is generally greater in areas that are altered by man, or if native fish species are depauperate (Ross 1991). Both conditions exist in the Goulburn Catchment. In North America, non-native fish species can almost completely replace native species in highly altered rivers (Brown *et al.* 2002). Therefore, the loss of species diversity upstream of the Goulburn Catchment, but the similar abundances between reaches suggests that alien species may have replaced the lost native species.

Although the successful establishment of alien species is not a direct result of river regulation, the environmental conditions established are often more appropriate for alien species. Mechanisms that can lead to domination of alien species in regulated rivers include the elimination of suitable spawning habitat and the reduction of habitat for early life stages of fishes (Cadwaller 1978; Marchetti and Moyle 2000). Populations of alien species can prey directly on native fish, compete with native species for resources such as food and habitat, alter habitat, and introduce foreign pathogens to the native fish population (Ross 1991; Arthington *et al.* 1997). There is evidence that native Australian species are adversely affected by alien species, with some effects being exacerbated by flow regulation (Arthington *et al.* 1997).

In the upper main channel of the Goulburn, the altered flow regime has also lead to reduced flooding of wetlands, which act as important nursery areas, and loss of low flows during summer and spring, which coincides with the reproductive season of Australian native fish. Change in flow regime was also an important factor in non-native fish becoming established in Putah Creek, California (Marchetti and Moyle 2001). Continual stocking of Salmonid species for recreational reasons in the upper section of the lower Goulburn Catchment also exacerbates the loss of native species. Data suggests brown trout (*Salmo trutta*) can be found in the upper Catchment throughout the year and have self-sustaining populations in select tributaries (DNRE 2000a).

At and below Lake Nagambie, habitat generalists, such as Gambusia (*Gambusia holbrooki*), common carp, (*Cyprinus carpio*), goldfish (*Carassius auratus*) and redfin perch (*Perca fluviatilis*), proliferate in regulated conditions. The highly regulated Campaspe River, also in northern Victoria, has a highly degraded fish fauna and is dominated by common carp and redfin perch (Cadwaller 1978; Humphries and Lake 2000). The success of these alien species in rivers is enhanced due to depauperate populations of native fish and human alteration of systems (Ross 1991).

Predictive Model of Risk Factors to Native Fish

Multivariate statistics are ideal for describing fish communities in the Goulburn Broken Catchment, but models have limited predictive capacity. The graphical modelling technique, Bayesian networks, was used to further describe risk factors, and to predict responses in native fish abundance and diversity in current environmental conditions and pre- and post-management interventions.

<u>Bayesian network models</u>

BNs are probabilistic networks that support reasoning under uncertainty. In risk assessment, uncertainty can arise from lack of precise knowledge regarding the model structure and input parameters (Brand and Small 1995). BNs are used in a variety of applications to establish causal relationships between key factors and final outcomes, and maintain clarity by making causal assumptions explicit (Stow and Borsuk 2003) They are particularly useful for uncertainty analysis as they have the ability to consider inadequate knowledge or understanding of system processes, inherent randomness, subjective judgement and vagueness in parameter estimation, disagreement, measurement error and sampling error (Morgan and Henrion 1990).

BNs are intuitive graphical models. They consist of a directed acyclic graph with an associated set of conditional probability distributions used to represent linkages (Reckhow 2002). Probabilities can be estimated using expert knowledge, empirical data, or both (Marcot *et al.* 2001; Rieman *et al.* 2001). Network probabilities are updated using Bayes' theorem. BNs are often used for analyzing and communicating causal assumptions not easily expressed using mathematical notation (Pearl 2000).

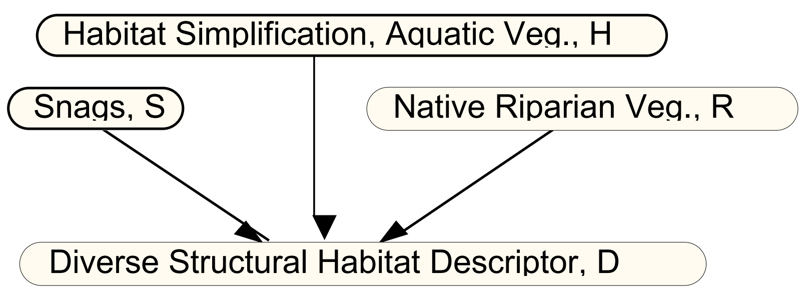
In ecology, modelling of processes using Bayesian networks is particularly ideal as Bayesian inference updates scientific knowledge as new information is made available (Reckhow 2002). This type of iterative improvement of models enables better accuracy in model prediction and fits into the ecological risk assessment paradigm.

A review of modelling methods was undertaken in the initial part of this study to determine what modelling approach would best meet the objectives of this study. The BN modelling approach was found to be the most robust for the needs of this project. BN models do not substitute for empirically based, quantitative, stochastic analyses of population demography, genetics, and persistence such as those used in population viability analysis (PVA). Rather, the BN models have the advantage of complementing PVA models (Marcot *et al.* 2001). As is the case with this study, BNs are most useful when empirical data on population trends, recruitment success and demography are unavailable, and PVA models cannot be constructed.

Subsequently, the BN approach was considered to be the optimal modelling option for this study, particularly as the final product had to form part of an iterative process whereby it can be updated as new information is made available. BNs are also to incorporate both expert opinion and data, incorporate limited and incomplete datasets, and identify priority risks to fish and key knowledge gaps.

BNs - Background
Bayesian networks are made up of a collection of nodes that represent environmental states or processes. Arrows represent causal dependencies between nodes, and a probability distribution that describes the relative likelihood of each value, conditional on every possible combination of values of its parents. If a node has no parents, it can be described probabilistically by a marginal probability distribution (Borsuk *et al.* Draft 2002).

For example, in the following network, round nodes represent important system variables and causal dependencies are represented by arrows:



The final node 'D' represents a joint distribution between parental variables, and is defined as:

$$P(S,H,R,D) = P(D|S,H,R)P(S)P(H)P(R)$$

Bayesian networks exploit the distributional simplifications of the network structure by calculating how probable certain events are, and how these probabilities can change given subsequent observations or predict change given external interventions (Borsuk *et al.* Draft 2002). A prior (unconditional) probability represents the likelihood that an input parameter will be in a particular state; the conditional probability calculates the likelihood of the state of a parameter given the states of input parameters affecting it; and the posterior probability is the likelihood that parameter will be in a particular state, given the input parameters, the conditional probabilities, and the rules governing how the probabilities combine. The network is solved when nodes have been updated using Bayes' Theorem:

$$P(A|B) = \frac{P(B|A)\, P(A)}{P(B)}$$

where P(A) is the prior distribution of parameter, A. After collection of data B, P(A|B) represents the posterior distribution, given the new knowledge.

To determine how probabilities change in response to external interventions, such as management actions, the simplest intervention is to enter evidence by assigning a fixed distribution to the parameter of interest. Thus, the original function is assigned a new function that specifies a value, with other variables being kept the same (Borsuk *et al.* Draft 2002). The new model represents the systems behaviour under the intervention and can be solved for the other variables to determine the net effect of the specified intervention.

BN construction process

A BN was constructed using the information gathered during the data aggregation and description step, from the literature and from extensive expert elicitation.

Expert elicitation was carried out over 2 workshops (documents produced as part of workshops 1 and 2 are in Milestones 3 and 4 respectively). Workshop 1 was conducted in order to develop a conceptual model (Figure 7) showing the variables influencing native fish communities in the catchment, and to develop endpoints for the model. Workshop 2 was used to refine the structure of the model, and to quantify relationships between variables in the model. More information about workshops can be found in the latter sections of this report.

The modelling software Netica (Norsys, Inc.) was used to construct the Bayesian network. Netica performs both standard belief updating and updating using the EM algorithm, solving the network by finding the posterior probability for each node. Netica assumes that the conditional probabilities are independent.

- BN structure

Clearly, the Goulburn Broken Catchment is a complex system with multiple factors interacting and influencing fish communities (Figure 7). The mechanistic relationships within this domain have not been characterised previously. Thus the Bayesian network modelling approach is being used to graphically represent the independent and interacting variables influencing fish communities. The relationships between variables are described probabilistically and account for any uncertainties.

The first step used to construct the Bayesian network was to develop the causal structure, with relevant variables (nodes) and dependencies. The network structure needed to be flexible in representing multiple scales of interest. The physical and biological processes that strongly influence diversity and abundance of native fish were identified in collaboration with stakeholders, and used to develop a conceptual model. The Bayesian network structure (Figure 8) represents a simplified version of a conceptual model constructed using the input from expert stakeholders.

Using the approach of (Borsuk *et al.* Draft 2002), the important criteria for inclusion of variables in the Bayesian network were, is the variable either: 1) manageable, 2) predictable, or 3) observable at the scale of the management problem. If the variable from the conceptual model did not meet one of these criteria, it was not included. In the final model, the variables represent the key factors in the Goulburn River that are recognised in the scientific literature and by stakeholders as controlling native fish abundance and diversity. The variables of the Bayesian network are tractable, being quantified using available information. In a Bayesian network, processes or factors that are unknown form part of the predictive uncertainty described in probability distributions (Borsuk *et al.* Draft 2002).

The Bayesian network developed in this study (Figure 9) is composed of 4 sub-models that are integrated in the two final ecological endpoints. Sub-models describe water quality, hydraulic habitat, structural habitat, and biological potential.

- Network variables

In order to represent continuous distributions in the BN, nodes were discretised into sub-ranges. True continuous relationships were not utilised as the data available was not strong enough to ascertain distributions. Where possible, nodes were discretised according to existing guidelines and classifications (Table 7). The remaining nodes were discretised based on expert opinion. The data incorporated into the model is obtained from multiple routine monitoring programs, as detailed in previous reports and table 8. The data is incorporated into the model as case data, and is represented in the network as probability bars (Figure 9). In the absence of monitoring data, probabilities are equally distributed.

In addition to the data nodes, there are type, site and time nodes. The type node relates to the spatial areas of interest in the study, as identified in the Phase 1 NPIRD report. These are below Eildon to Trawool (upper region), Lake Nagambie/Goulburn Weir (mid region), and Murchison to the confluence with the Murray (lower region). The main channel and tributaries are also considered independently. These areas within the catchment also have distinct fish communities, as detailed previously. The type node in the network further divides the site node (Table 1). By selecting a site or type the relevant information from this area (eg. flow characteristics, water quality, etc.) is shown.

Included as part of the model, and as identified in both the site and type nodes, is the Broken Catchment. The Broken Catchment information was included in the model only to give the data learning process more ‘experience’ in representing relationships between endpoint nodes and the associated environmental conditions. Future studies could explore breaking down this section of the model.

In addition to being spatially explicit, the model also considers risks to fish over specified temporal periods, being 1 and 5 years. The model is a static representation of these time scales, thus the model is not dynamic. No further temporal components were added to the model, given that data simply was not robust enough to work over greater temporal scales. Also, further expert elicitation for additional temporal periods were not considered beyond workshop 2 as the capacity of our experts had been extended to the limit in the initial workshops.

- Conditional Probability Distributions

In order to quantify the relationships between nodes, conditional probabilities are utilised. Conditional probability distributions can be obtained three ways; they can be judged directly from experts, obtained from scientific literature, or obtained by fitting a network to a set of observed cases (Henrion *et al.* 1996).

Table 7: Methodology used to discretise nodes, and states of these nodes.

Node	Discretisation methodology	States
Barrier	Based on classification in ISC	None Complete Deep Complete Shallow Inundated
Anthropogenic inputs	Expert knowledge	Low Medium High
Dissolved Oxygen	Expert knowledge (workshop II)	Extreme Low (0 – 40 %) Normal (40 – 110%) Extreme High (110 – 200%)
Salinity	Clunie *et al.* (2002) - fish data only	Low (0 – 1000 mg/L) Medium (1000 – 5600 mg/L) High (5600 – 10000 mg/L)
Turbidity	Expert knowledge (workshop II)	Low (0 – 100 NTU) Medium (100 – 1000 NTU) High (1000 – 10000 NTU)
Temperature modification (°C) from natural	Ryan *et al.* (2001) Modelling of natural temperatures, and relating to temperatures required for spawning (Koehn and O'Connor 1990)	No Change (0 – 2°C) Moderate (2 – 4°C) Major (4 – 10°C)
Seasonal Flows – percentage change from natural	Collection of pre dam and post dam data, calculating % change in means Classification in ISC (DSE 2002)	Extreme Decrease (0 – 25%) Decrease (25 - 75%) No Change (75-125%) Increase (125 - 175) Extreme Increase (175 – 1000%)
Floodplain inundation	Gippel and Finlayson (1993)	Yes No
Macroinvertebrates	AUSRIVAS score in ISC > 0.80 4 0.79-0.6 3 0.59-0.4 2 0.39-0.2 1 < 0.2 0	Low (0 – 1) Medium (1 – 3) High (3 – 4)
Loss of fish	Fishing Licenses	Low High
Stocking Rate	DPI	None Low High
Snags Habitat Simplification Native Riparian Vegetation	Classification in ISC (DSE 2002)	Low/Complete/Degraded Medium/Some/Moderate High/None/Intact
Current & Future Abundance	Percentiles of populations in the Goulburn catchment Percentile 60%: Draft native fish strategy - native spp. make up 60% or more of population	< 60% Low (0 – 54) > 60% High (54 – 500)
Alien threat	Percentiles of populations in the Goulburn catchment Percentile 40%: Draft native fish strategy	< 40% Low (0 – 15) > 40% High (15 – 500)
No. of Migratory spp. Migratory spp.	Percentiles of populations in the Goulburn catchment	< 50% Low (0 – 3) > 50 % High (3 – 15)

Table 8: Sources of data for posterior calculations

Variable	Information source
Barrier	ISC findings (DNRE 2002)
pH, Dissolved Oxygen, Turbidity, Salinity	Victorian Water Quality Monitoring Network (DNRE 2002)
Toxicants	Subjective node based on expert knowledge
Temperature modification	Modelling of natural temperatures Data in (Gippel *et al.* 1993)
Hydraulic Habitat (% change from natural)	Collection of pre dam and post dam data (DSE 2002), own calculations of percentage change in means (Eildon, Murchison) Other sites: ISC information – modelling of natural flows (DSE 2002)
Native Riparian Vegetation, Habitat Simplification & Aquatic vegetation, Snags	ISC findings (DSE 2002)
Current Abundance, Alien Threat, No. of Migratory spp., No. of Non-Migratory spp.	Data collected by: - Marine and Freshwater Research Institute (DPI) - Arthur Rylah Institute (DSE) - Murray Darling Freshwater Water Research Institute (MDFRC) - Lake Nagambie Angling Club
Stocking	Information from DSE/DPI
Migration	Based on the type of barrier present

In this study, all approaches were utilised and probability distributions were ascertained over two iterations. The first iteration used expert opinion and relationships described in the literature to calculate conditional probabilities. The second iteration produced spatially explicit networks, and used relationships described in the physical and biological data for each site or region to describe relationships between variables. In order to test the robustness of the expert elicitation process, shifts in probabilities were measured in the second step.

BN Iteration One

As stated earlier, the Bayesian network developed in this study is composed of 4 sub-models. Parent nodes for each sub-network feed into mediating descriptor nodes, whose outcomes are calculated by conditional probability relationships. The conditional probabilities of the descriptor nodes for physical data variables ('Water Quality Descriptor' 'Hydraulic Habitat Descriptor' 'Structural Habitat Descriptor') are based on an additive model calculated from raw data incorporated into parent nodes. This approach is similar to that used in the Index for Stream Condition. The conditional probability relationships of the descriptor node for the biological data variables ('Biological Potential Descriptor') are based on expert opinion and relationships detailed in the literature.

All descriptor nodes feed into the model endpoints 'Future abundance' and 'Future diversity' (Figure 8). The 'Future diversity' endpoint is a function of 'Future abundance' and 'Current diversity'. In this iteration, the endpoints 'Future abundance' and 'Future diversity' were estimated using expert opinion and relationships described in the literature.

BN Iteration Two

To introduce the relationships embodied in the spatially specific physical and biological monitoring records, conditional probabilities were updated from the data using the EM algorithm (Demster *et al.* 1977). Thus, expert elicitation was used for establishing prior probabilities, and monitoring data used as posterior probabilities. The EM algorithm is useful for incomplete data problems and is an iterative computation for calculating Maximum Likelihood Estimates. The networks produced in this process are specific to individual sites/reaches. Data (sources are identified in Table 8) was incorporated into the networks as a series of cases.

Monitoring data was organised into a series of cases that are incorporated into the network. Cases were arranged according to the fishery sampling date. Physical data was matched to each of the fishery sample dates. Time-based physical data could only be matched for water quality parameters pH, salinity, turbidity, and dissolved oxygen at routinely monitored sites, identified in Table 1. Biological and physical monitoring dates were matched to ensure they were within 7 days of one another. The remaining physical data related to the Index for Stream Condition survey conducted in 1999, and to the author's knowledge no other analogous surveys have been conducted. The frequency of sampling data for a site determines the number of cases incorporated into the nodes of the network, and the greater the certainty of probability distributions.

The final conditional probability relationships of the final endpoint node 'Future abundance' are based on expert opinion, relationships detailed in the literature, and relationships in data, whereas 'Future diversity' is based on only expert opinion and relationships detailed in the literature. An example of a network specific for Eildon is shown in Figure 10.

The results presented in this report are relevant to a temporal scale of 1-year only. Results for the 5-year temporal scale show similar trends, but with higher uncertainties in the predictive outputs.

Sensitivity Analysis
To assess the reliability of the network and have a detailed insight into the robustness of the network's output, the network was subjected to sensitivity analysis (Coupe and van der Gaag 2002). Two types of sensitivity analysis were performed on the network: sensitivity to parameters and sensitivity to findings. Sensitivity analyses used to identify which parts of the network need better quantification (quantitative component) and to identify which parts of the network structure (qualitative component) need improvement. Analyses for sensitivity to findings and sensitivity to parameters were conducted on the network at each iterative stage of development, as recommended in (Coupe *et al.* 2000).

An example of sensitivity to parameters output is given in figure 11. Overall this test demonstrated that the model outputs were insensitive to change and the structure of the network is robust. These results are presented in detail in Appendix 3 and are discussed further below. Sensitivity to findings analyses were performed by simultaneously investigating the changes of the probabilities in parameters of interest. The probability of each variable in the network was varied between 0 and 1, and the change in the node of interest was examined. This procedure allowed for the examination of the effects of inaccuracies in the model output.

Given that the BN is spatially explicit, findings for individual sites can be assessed using sensitivity analysis. Sensitivity analyses were performed on all parts of the network, and full results are presented only for one-way sensitivity analysis of the two model endpoints, 'Future abundance' and 'Future diversity' (Appendix 3). These findings can be used to identify priority risks to fish and prioritise future research, as discussed in latter sections. Sensitivity analyses are a powerful tool for identifying priority risks for both a system in its current state, or in a system where management interventions have been made.

In collaboration with the Computer Science and Software Engineering (CSSE) group at Monash University, windows-based programs to conduct both sensitivity to findings and sensitivity to parameters have been developed as support tools for constructing Bayesian networks. A conceptual diagram and decision tree to guide future development of Bayesian networks, informed by the experience of building the native fish Bayesian network, are being developed to assist future modelling studies.

Model validation and accuracy
To test model performance, two types of analyses were conducted. First a qualitative analysis was done and the catchment fisheries data plotted against model predictions. The second analysis was quantitative, and the predictive accuracy of the model was calculated using a data split.

- Qualitative analysis

The site-specific BN model shows a static representation of the physical, chemical and biological characteristics of the site of interest. By selecting Eildon the model shows the predictions of abundance and diversity at this site under current conditions (Figure 10). This was conducted for all sites and the future abundance (Figures 12a and 12b) and future diversity (Figures 13a and 13b) data was plotted against the model outputs.

The trends between bar and line graphs are well maintained in the Goulburn main channel throughout the catchment. In the tributaries, the plot does not identify high abundances and diversities in the data, but given the particularly poor data availability for these tributaries, this is not surprising. Additional data is required at these sites to improve the predictive accuracy of the model.

- Quantitative analysis

To test the predictive accuracy of the model, case data was split so that 80% was used for training and 20% used for testing. Predictive accuracy tests were conducted in collaboration with CSSE. Tests were conducted on the entire network, but for the purposes of this section of the report, results are presented for the endpoint nodes only. Full results can be found in Appendix 4. The results indicate that:

- 'Future abundance' error rate = 10.71%
- 'Future diversity' error rate = 0% (all low)

Error rates are low, but due to the lack of variability in the data, the full spectrum of variability in the network cannot be tested. Predictive accuracy of the model should be tested further, particularly by determining model accuracy pre- and post- management interventions. Further case data representing healthy fish abundance and diversities and the associated environmental conditions are required for this model to gain more experience, it is unlikely that this data would be available in the Goulburn or Broken Catchments. To compensate for this, currently the model is relying on expert elicitation.

Testing management alternatives

To test the outcome of management actions on fish communities using the BN, evidence can be entered directly onto a node of the network. Bayes's Theorem is used to update the variable prior probabilities. These probabilities are now the posterior probabilities.

As an example of how management alternatives can be tested using the model, different site conditions were entered into the network as evidence. For the purposes of this report, scenarios tested were conducted for Eildon, located in the upper main channel. Interventions included improving water quality by mitigation of temperature changes at Eildon Dam without flow mitigation (Figure 14), with minor changes in summer-autumn flows (Figure 15), with return of flows to natural and retention of low turbidity (Figure 16). The outcome of this scenario is still weighted towards low future abundance. The primary reason for this is the current abundance is low. An intervention was included at turbidity as the model assumed turbidity levels would be increased due to reduction in current summer flows as a result of flow mitigation. The BN model is not dynamic, but it accurately reflects that it will take time for a native fish community to increase in abundance.

A scenario that considers a return of flows to natural, maintenance of low turbidity and an increase in current fish abundance results in a higher predicted future abundance (Figure 17). To improve fish community predictions beyond the outcome in Figure 17, sensitivity analysis indicates structural habitat variables need attention (results not shown). After testing each scenario an improvement in fish abundance was observed, while accounting for uncertainties in these predictions. Fish diversity was also improved, but only to a minor extent.

Primary driver of native fish communities

A tool being developed by the CSSE group (Causal Minimum Message Length - CaMML) as part of their own research agenda is the use of data mining techniques to establish the causal relationships between variables in a dataset. Using a the technique 'Minimum Message Length' (MML) the simplest model structure to predict fish communities in the catchment, as embodied in the physical, chemical and biological case data, was identified (Figure 18).

The CaMML modelling program identified the presence or absence of a barrier being the primary driver of fish abundance in the catchment. The CaMML model for fish abundance as embodied in the data, is shown in Figure 18. From an academic perspective, this relationship is of great interest. From a management perspective, barrier removal is unlikely to be a viable solution and the range of manageable variables in the catchment need to be investigated.

Prioritisation/Ranking of Risk Factors

As stated previously, sensitivity analysis can be used to identify variables in a network that have the greatest influence on network findings. The ranking of variables can be used to identify priority risks to native fish abundance and diversity. These variables also indicate where better quantification in the network should be investigated. Where variables are not satisfactorily quantified, key knowledge gaps exist. Sensitivity findings differ for each part of the catchment, and accordingly, priority risks also differ.

The following discussion groups the sensitivity results according to location in the catchment. Only the most influential variables to both native fish abundance and diversity, in order of importance, are shown. The full results for sensitivity analyses for each site are presented in Appendix 3.

In the Bayesian network, the causal link between the variables future abundance and future diversity results in these nodes having the greatest influential weighting on one another. The relationship between these parameters is excluded from the risk ranking tables (Tables 9 to 13). Future diversity is a child node of current diversity, and is the most sensitive parameter for all sites, as shown in tables 9 to 13.

Upper main channel (Table 9)

Water quality (primarily under the control of temperature modification) and the changed hydrology of the upper part of the lowland Goulburn main channel appear to be the variables primarily influencing native fish abundance. Other variables of importance are the biological potential and the barrier.

Water quality and hydraulic habitat variables are important variables for determining future diversity in this reach, reflecting the causal link between future abundance and future diversity.

Upper tributaries (Table 10)

Findings for the future abundance variable in the upper tributaries are primarily under the control of the biological potential and water quality variables, but with hydraulic habitat and water quality being of importance in Sunday Creek. Biological potential is influenced by potential recruitment of native fish and the current abundance. Water quality is influenced by turbidity, and to a lesser extent, dissolved oxygen and pH. Hydraulic habitat is also an important determinant of future abundance.

Findings for future diversity are as described in future abundance.

Table 9: *Upper main channel*

Location	Future Abundance	Future Diversity
Eildon	Water Quality Habitat Descriptor	Current Diversity
	Hydraulic Habitat Descriptor	Water Quality Habitat Descriptor
	Natives Biological Potential Descriptor	Hydraulic Habitat Descriptor
	Temperature modification	Migratory species
	Barrier	Connectivity
Alexandra	Water Quality Habitat Descriptor	Current Diversity
	Hydraulic Habitat Descriptor	Water Quality Habitat Descriptor
	Temperature modification	Hydraulic Habitat Descriptor
	Barrier	Barrier
	Change in Avr flows Summer-Autumn	Temperature modification
Yea	Water Quality Habitat Descriptor	Current Diversity
	Hydraulic Habitat Descriptor	Water Quality Habitat Descriptor
	Temperature modification	Hydraulic Habitat Descriptor
	Barrier	Migratory species
	Potential Recruitment	Barrier
Trawool	Water Quality Habitat Descriptor	Current Diversity
	Hydraulic Habitat Descriptor	Water Quality Habitat Descriptor
	Temperature modification	Hydraulic Habitat Descriptor
	Barrier	Barrier
	Change in Avr flows Summer-Autumn	Migratory species

Table 10: *Upper tributaries*

Location	Future Abundance	Future Diversity
Rubicon	Water Quality Habitat Descriptor Natives Biological Potential Descriptor Turbidity Potential Recruitment Hydraulic Habitat Descriptor	Current Diversity Water Quality Habitat Descriptor Natives Biological Potential Descriptor Turbidity Potential Recruitment
Taggerty	Natives Biological Habitat Descriptor Water Quality Habitat Descriptor Hydraulic Habitat Descriptor Current Abundance Potential Recruitment	Current Diversity Natives Biological Potential Descriptor Water Quality Habitat Descriptor Hydraulic Habitat Descriptor Connectivity
Acheron	Natives Biological Potential Descriptor Water Quality Habitat Descriptor Hydraulic Habitat Descriptor Potential Recruitment Current Abundance	Current Diversity Natives Biological Potential Descriptor Water Quality Habitat Descriptor Hydraulic Habitat Descriptor Connectivity
Murrundindi	Natives Biological Potential Descriptor Water Quality Habitat Descriptor Hydraulic Habitat Descriptor Potential Recruitment Current Abundance	Current Diversity Natives Biological Potential Descriptor Water Quality Habitat Descriptor Hydraulic Habitat Descriptor Migratory species
Yea	Natives Biological Potential Descriptor Water Quality Habitat Descriptor Hydraulic Habitat Descriptor Potential Recruitment Current Abundance	Current Diversity Natives Biological Potential Descriptor Water Quality Habitat Descriptor Hydraulic Habitat Descriptor Potential Recruitment
King Parrot	Natives Biological Potential Descriptor Water Quality Habitat Descriptor Hydraulic Habitat Descriptor Potential Recruitment Current Abundance	Current Diversity Natives Biological Potential Descriptor Water Quality Habitat Descriptor Hydraulic Habitat Descriptor Potential Recruitment
Sunday	Hydraulic Habitat Descriptor Water Quality Habitat Descriptor Natives Biological Potential Descriptor Turbidity pH	Current Diversity Hydraulic Habitat Descriptor Water Quality Habitat Descriptor Natives Biological Potential Descriptor Migratory species
Hughes	Water Quality Habitat Descriptor Natives Biological Potential Descriptor Potential Recruitment Hydraulic Habitat Descriptor Turbidity	Current Diversity Water Quality Habitat Descriptor Natives Biological Potential Descriptor Potential Recruitment Hydraulic Habitat Descriptor

Mid main channel (Table 11)
Findings for the future abundance variable at Lake Nagambie/Goulburn Weir are primarily under the control of the biological potential and water quality variables. Biological potential is most sensitive to the current abundance and potential recruitment variables. Water quality is identified as an important variable as no water quality monitoring data was entered into this site due to the absence of VWQMN and ISC information. This missing information can be considered to be an important knowledge gap. Hydraulic habitat is also an important determinant of future abundance.

Biological potential, water quality and the current population of migratory and non-migratory species influence findings for future diversity.

Lower main channel (Table 12)
Findings for future abundance in the lower main channel are primarily under the influence of the biological potential and water quality variables. Biological potential is once again influenced by potential recruitment of native fish and the current abundance. Water quality is again most sensitive to turbidity, dissolved oxygen and pH, with neither of these variables dominating. Hydraulic habitat is also an important determinant of future abundance.

The findings for future diversity are variable among sites with no clear trend. Water quality and biological potential are of importance at all sites. Other priority risk factors are variable between sites.

Lower tributaries (Table 13)
Findings for future abundance in the lower tributaries are primarily under the influence of the biological potential and water quality variables. In the Creighton and Brankeet Creeks potential recruitment and water quality variables are of priority importance. Biological potential is again most sensitive to potential recruitment of native fish and the current abundance. Water quality is influenced primarily by turbidity. Hydraulic habitat is also an important determinant of future abundance.

The findings for future diversity are largely impacted by the variables water quality and biological potential. Other factors include hydraulic habitat, and in Sevens Creek the current population of migratory and non-migratory species influence findings.

Relationships between Risk Factors and Identified Risk Quantified
In the Phase 1 report, it was proposed that risk curves be generated as part of the Phase 2 study. It was established early in this study that the data available on native fish communities in general, let alone in the Goulburn Broken Catchment, was not suitable to establish empirical relationships. For this reason, the Bayesian approach was taken.

The Bayesian approach utilised probabilistic estimations to derive the relationships between habitat variables and native fish abundance and diversity, thus mathematical functions were not utilised to describe relationships. To facilitate the process variables of probability estimation, variables were discretised. Therefore the type of theoretical relationships proposed in the Phase 1 report cannot be generated as relationships represented in the BN model are neither univariate or continuous. Given that there are multiple interacting factors influencing fish abundance and diversity, generating univariate relationships would be misleading. For examples of the types of relationships generated between fish abundance and risk factors in the BN, refer to figure 19.

Table 11: *Mid main channel*

Location	Future Abundance	Future Diversity
Lk Nagambie / Goulburn Weir	Natives Biological Potential Descriptor Water Quality Habitat Descriptor Hydraulic Habitat Descriptor Current Abundance Potential Recruitment	Current Diversity Natives Biological Potential Descriptor Water Quality Habitat Descriptor Migratory species Non-migratory species

Table 12: *Lower main channel*

Location	Future Abundance	Future Diversity
Murchison	Natives Biological Potential Descriptor Water Quality Habitat Descriptor Potential Recruitment Hydraulic Habitat Descriptor Current Abundance	Current Diversity Natives Biological Potential Descriptor Water Quality Habitat Descriptor Potential Recruitment Hydraulic Habitat Descriptor
Shepparton	Water Quality Habitat Descriptor Natives Biological Potential Descriptor Hydraulic Habitat Descriptor pH Dissolved Oxygen	Current Diversity Non-migratory species Migratory species Natives Biological Potential Descriptor Water Quality Habitat Descriptor
McCoys Br	Natives Biological Potential Descriptor Water Quality Habitat Descriptor Hydraulic Habitat Descriptor Current Abundance Potential Recruitment	Current Diversity Natives Biological Potential Descriptor Migratory species Water Quality Habitat Descriptor Non-Migratory species
Undera	Water Quality Habitat Descriptor Natives Biological Potential Descriptor Hydraulic Habitat Descriptor Potential Recruitment Current Abundance	Current Diversity Natives Biological Potential Descriptor Water Quality Habitat Descriptor Hydraulic Habitat Descriptor Migratory species
Echuca	Natives Biological Potential Descriptor Water Quality Habitat Descriptor Turbidity Hydraulic Habitat Descriptor Potential Recruitment	Current Diversity Water Quality Habitat Descriptor Natives Biological Potential Descriptor Turbidity Hydraulic Habitat Descriptor

Table 13: *Lower tributaries*

Location	Future Abundance	Future Diversity
Pranjip	Water Quality Habitat Descriptor Natives Biological Potential Descriptor Turbidity Hydraulic Habitat Descriptor Potential Recruitment	Current Diversity Water Quality Habitat Descriptor Natives Biological Potential Descriptor Turbidity Hydraulic Habitat Descriptor
Creightons & Brankeet	Water Quality Habitat Descriptor Potential Recruitment Natives Biological Potential Descriptor Hydraulic Habitat Descriptor Turbidity	Current Diversity Water Quality Habitat Descriptor Potential Recruitment Natives Biological Potential Descriptor Hydraulic Habitat Descriptor
Castle	Natives Biological Potential Descriptor Water Quality Habitat Descriptor Hydraulic Habitat Descriptor Potential Recruitment Current Abundance	Current Diversity Natives Biological Potential Descriptor Water Quality Habitat Descriptor Hydraulic Habitat Descriptor Potential Recruitment
Sevens	Water Quality Habitat Descriptor Natives Biological Potential Descriptor Hydraulic Habitat Descriptor Turbidity Potential Recruitment	Current Diversity Water Quality Habitat Descriptor Migratory species Non-Migratory species Natives Biological Potential Descriptor

Ecological Effects Tables
Qualitative ecological effects tables were prepared for each reach of importance identified in the Phase 1 NPIRD report, the Goulburn main channel (Tables 14 to 16) and tributaries (Tables 17-18) are considered independently.

Effects tables show the environmental stressors of importance, provide an estimate of risk (probability adverse effect will occur) to native fish for each stressor, and give the level of uncertainty for that estimate. Estimates were developed using BN model findings, existing knowledge of stressors and fisheries data. The level of uncertainty in that knowledge is identified for each parameter. In many cases, the level of uncertainty associated with a variable (eg. turbidity and salinity) is high as few streams are monitored. Also, knowledge of the relationships and associated thresholds between model variables and native fish endpoints is still poor.

Expert Stakeholder Workshops
As detailed in previous milestone reports, two expert workshops were conducted as part of this study.

Workshop 1
The objectives of workshop 1 were: to refine the conceptual model proposed in Phase 1; discuss proposed spatial and temporal scales; identify assessment and measurement endpoints; discuss approaches to modelling; define key knowledge gaps; and develop links with stakeholders. All these objectives were achieved.

Workshop 2
The objectives of workshop 2 were: to review the progress of the project to date; to review the structure of the Bayesian network produced for native fish abundance and diversity in the Goulburn Broken catchment; to incorporate the knowledge of our expert panel into the network; to identify key knowledge gaps in the model and specify how these gaps might be filled.

My initial reaction to workshop 2 was that the process was of mixed success. The expert elicitation for quantifying links in the network was only broadly covered, and there was criticisms regarding the model structure and outputs. However, in hindsight, the workshop 2 expert quantification processes provided good grounding for establishing the initial priors of the network. Using Bayesian network technology, we have been able to build upon the values elicited by experts using actual data, thus improving the robustness and accuracy of the model. This process of elicitation and data learning is used routinely in the field of Bayesian networks, but rarely in ecological applications.

Using sensitivity analysis, the factors in the model that require better quantification have been identified. This has enabled knowledge gaps to be identified, and recommendations for future studies and monitoring to be made. This is discussed in detail in latter sections.

Table 14: Goulburn River - Eildon to Trawool.

Parameter		Risk (Probability)	Uncertainty
Water Quality	Temperature	H	L
	Turbidity	L	L
	pH	L	L
	DO	L	L
	Salinity	L	L
	Excess nutrients	L	L
	Toxicants/Organic C	L	L
Barriers	Change in flow regime	H	L
	Prevent migration	H	L
In-stream	Geomorphology	M	M
Structural	Riparian vegetation	M	M
Habitat	Snags	M	M
Alien Species		H	M

Table 15: Goulburn River – Lake Nagambie/Goulburn Weir.

Parameter		Risk (Probability)	Uncertainty
Water Quality	Temperature	L	M
	Turbidity	L	H
	pH	L	H
	DO	L	H
	Salinity	L	M
	Excess nutrients	L	L
	Toxicants/Organic C	L	L
Barriers	Change in flow regime	H	L
	Prevent migration	H	M
In-stream	Geomorphology	M	M
Structural	Riparian vegetation	M	M
Habitat	Snags	M	M
Alien Species		H	M

Table 16: Goulburn River – Murchison to Murray confluence.

Parameter		Risk (Probability)	Uncertainty
Water Quality	Temperature	L	L
	Turbidity	M	H
	pH	L	L
	DO	L	L
	Salinity	L	M
	Excess nutrients	L	L
	Toxicants/Organic C	L	L
Barriers	Change in flow regime	H	L
	Prevent migration	M	M
In-stream	Geomorphology	L	M
Structural	Riparian vegetation	M	M
Habitat	Snags	M	M
Alien Species		H	M

Table 17: Tributaries - Eildon to Lake Nagambie.

Parameter		Risk (Probability)	Uncertainty
Water Quality	Temperature	L	L
	Turbidity	M	H
	pH	L	L
	DO	L	L
	Salinity	L	M
	Excess nutrients	L	L
	Toxicants/Organic C	L	L
Barriers	Change in flow regime	M	L
	Prevent migration	H	L
In-stream	Geomorphology	M	M
Structural	Riparian vegetation	M	M
Habitat	Snags	M	M
Alien Species		H	M

Table 19: Tributaries – Murchison to Murray confluence.

Parameter		Risk (Probability)	Uncertainty
Water Quality	Temperature	L	L
	Turbidity	H	H
	pH	L	L
	DO	L	L
	Salinity	L	M
	Excess nutrients	L	L
	Toxicants/Organic C	L	L
Barriers	Change in flow regime	H	L
	Prevent migration	H	L
In-stream	Geomorphology	M	M
Structural	Riparian vegetation	M	M
Habitat	Snags	M	M
Alien Species		H	M

In workshop 2, there were criticism of model structure and outputs. This was due to a different set of experts from Workshop 1 being involved in Workshop 2. Workshop 1 was designed to determine the purpose of the model. It was decided that the model should be general for native fish (not species specific) and it should not attempt to be an ecosystem model, as this was considered to be a task beyond the scope of this study.

The main lessons from the elicitation process were:

- Keep the same participants for Workshop 1 and 2 (this was not possible in this study due to time commitments of invitees [2-day workshop] and the time structure of this project),
- Where this is not possible, investigate a general one-day "education workshop" followed by one-to-one elicitation
- In group situations, if there is disagreement between experts, have individual elicitations on hand outs (this was attempted in Workshop 2, but the structural changes and re-changes over the 2 days made this impossible to do on the day),
- Investigate doing a more extended elicitation process or reduce the size and complexity of the model.

One point to note, elicitation requires a heavy commitment from experts, especially for a model of this size and complexity. I believe the capacity of our experts was extended to the maximum over the 2-day workshop.

Future work

In order to satisfy the requirements of an ecological risk assessment, an important attribute of models is they need to be iterative. Compared to other model types, Bayesian networks can be updated relatively easily. Both the structural and quantitative components of a model can be improved as new knowledge becomes available. This is particularly valid in a management context. As management actions are undertaken in the Goulburn Broken Catchment, the model can be updated to reflect pre- and post- fish community responses.

In workshop 1, stakeholders identified successful recruitment as a desirable endpoint for the native fish model. This was not considered achievable in this study given the paucity of data available. On the request of expert stakeholders in workshop 2, recruitment was made explicit in the model. An important area of research in the CRCFE is the investigation of factors contributing to successful recruitment. As the knowledge of conditions required for successful recruitment by native fish improves, the recruitment section of the BN could be expanded. Integration of information from the MDFRC into this model would be particularly beneficial. In the BN model, the level of successful recruitment was identified as an important variable in sensitivity analyses.

Another key information gap identified in the model was the effect turbidity is having on native fish communities, particularly in the mid and lower sections of the catchment. Once again, relevant study findings should be incorporated into the model as they become available. Uncertainty exists as many sites are not monitored for turbidity in the catchment, and the thresholds where fish are affected by turbidity are poorly described. This is also relevant for other important factors, including temperature changes and flow.

A desire of expert stakeholders in workshop 2 was that the model be species specific. At this stage the fisheries data available in the catchment is not comprehensive enough to be divided into species groups. In order for this to be done, a comprehensive fisheries survey in the catchment is required. Additionally, the knowledge of environmental factors influencing native fish species in the catchment is poorly understood, with expert knowledge and data being poor.

As stated earlier, the Broken catchment data was incorporated into the model simply for better quantification of the relationship between variables. There is the potential to expand the model to other lowland river systems, particularly in areas that have healthy native fish communities. The model in its current iteration has not had much experience with systems with healthy fish communities.

The BN produced is not a dynamic model. The model is static representations of fish abundance and diversity over both 1 year and 5 year time periods. In order to have a more dynamic representation of the system, an ecosystem model would be more appropriate. Bayesian dynamic networks require rich information sources, or a comprehensive expert understanding of how system component interacts with one another. One way of achieving this is to use deterministic physical and chemical models to inform the Bayesian network.

In the current iteration of the BN, only discrete probabilities are used to represent continuous relationships between interacting variables. Future iterations could investigate using continuous probability distributions. At the present time, the data available is not strong enough to develop a full understanding of these distributions. The use of distributions also limits the capacity of the model relationships to be updated using the EM algorithm, the learning technique used to update the model in this study. The model would also become more generic for systems, rather than being both generic for the catchment and specific for sites within the catchment as it is now.

Recommendations for future monitoring

In order for the BN model produced in this study to be applicable to the Catchment in the long term, it needs to be updated regularly. To improve the value of fisheries data for use in modelling, a series of recommendations can be made to those collecting data:

- Record date, site (Longitude/Latitude or Northing/Easting) and fish sampling technique(s);
- Use uniform methodologies (eg. electrofishing, large and small fyke nets) for sampling;
- Indicate the proportion of fish that are larvae, juveniles and adults, which will provide a limited indication of recruitment success;
- Incorporate basic water quality measurements in routine monitoring (eg. pH, dissolved oxygen, temperature, salinity, turbidity) and document methodologies;
- Include measurements of flow;
- Conduct physical habitat assessments (eg. snags, aquatic vegetation, evidence of sand slugs causing channel infilling, riffles or pools);
- Quantify all fish collected, not just target species or species of interest;
- If possible, conduct a rapid assessment of the health of microfauna populations;
- Enter information into a common database.

Improvements in the design of monitoring protocols will assist in validating model predictions and enabling better quantification of relationships between variables.

Summary
When constructing models for an ecological risk assessment, uncertainties can arise as a result of incomplete datasets for model parameterisation, as a result of subjective assessments from expert indecision or lack of consensus amongst experts. The representation of uncertainty in risk assessment is critical for assisting system managers faced with making decisions to decrease or eliminate risks.

The BN modelling approach proved to be a successful approach for modelling a system with poor data and high uncertainties. By utilising disparate data from various monitoring programs together with expert knowledge, the BN approach enabled the development of a description of native fish communities in their current state in the Goulburn Broken Catchment, and provides guidance as to how management actions in the catchment will affect native fish.

The process used to create the BN in this study has the potential to be applied to many other areas of ecology where high uncertainties exist. Many of the data learning techniques and model sensitivity tests used in this project are novel for this domain and proved to be highly successful. Given that the model building process also involved extensive interactions with expert stakeholders, included system managers, scientists and ecological modellers, stakeholders can claim intellectual ownership on the model and the final product and modelling approach are more likely to be accepted and adopted.

The BN model developed in this study, when used with other tools, has the potential to provide a powerful tool to support future decision making in the catchment. However, as outlined previously, the model needs regular updating to have an expanded life span, thus fitting into the adaptive management approaches utilised in the Goulburn Broken Catchment.

Project outputs

Conference Presentations

Pollino, C.A., Feehan, P., Grace, M., Hart, B. (2002) Using Ecological Risk Assessment to quantify the risks to fish in the Goulburn Broken Catchment. Australian Society for Limnology, 29 September – 30 October 2002, Margaret River. Platform presentation.

Pollino, C.A., Feehan, P., Grace, M., Hart, B. (2003) Quantifying the risks to fish in the Goulburn Broken catchment. Ninth International Conference on River Research and Applications, 6 - 11 July 2003, Albury. Poster presentation.

Pollino, C.A., Feehan, P., Grace, M., Hart, B. (2003) Quantifying the risks to fish in the Goulburn Broken catchment (Victoria, Australia) using Bayesian networks. Society of Environmental Toxicology and Chemistry (SETAC), 26 - 1 September 2003, Christchurch. Platform presentation.

Pollino, C.A., Feehan, P., Grace, M., Hart, B. (2002) Quantifying the risks to fish in the Goulburn Broken catchment (Victoria, Australia). Australian Society for Limnology, 1 –5 December 2003, Warrnambool. Platform presentation.

Invited Presentations

Pollino, C.A., Feehan, P., Grace, M., Hart, B., (2003) Adverse changes to the abundance and diversity of native fish in the Goulburn catchment. River & Catchment Health: Presenting current research in the Goulburn Broken catchment, 5 August 2003, Dookie, Victoria.

Refereed Publications

Pollino, C.A., Feehan, P., Grace, M., Hart, B.T. (submitted Nov 2003) Fish communities and habitat changes in the highly modified Goulburn Catchment, Victoria, Australia. *Marine and Freshwater Research*

Pollino, C.A., Woodberry, O., Feehan, P., Hart, B.T. (in prep.) Quantifying the risks to fish in the Goulburn Broken Catchment (Victoria, Australia) using Bayesian networks. To be submitted to *River Research and Applications* (Submit Mar 2004)

Woodberry, O., Nicholson, A., Korb, K., Pollino, C.A. (in prep.) A methodology for parameterising Bayesian networks: A case study in ecological risk assessment. To be submitted to the *Pacific Rim International Conference on Artificial Intelligence* (Submit Mar 2004). Paper will be a platform presentation and published in conference proceedings.

Un-Refereed Publications

Woodberry, O., Nicholson, A., Korb, K., Pollino, C.A. (in prep.) A methodology for parameterising Bayesian networks: A case study in ecological risk assessment. *Monash University Technical Report* (Submit Mar 2004)

Acknowledgements

Workshop participants:

Dr. Mike Stewardson, Wayne Fulton, Dr. John Douglas, Tarmo Raadik, Dr. Peter Gehrke, Prof. John Harris, Dr. Charles Todd, Dr. Paul Humphries, Prof. Sam Lake, Dr. Nick Bond, David Tiller, Dr. Simon Treadwell, Dr. Ann Nicholson, Owen Woodberry, Pat Feehan, Sophie Martin, Prof. Barry Hart, Dr. Mike Grace, Dr. Angus Webb, Terry Chan

Data suppliers

Department of Sustainability and Environment, Department of Primary Industries, Murray Darling Freshwater Research Centre, Lake Nagambie Angling Club

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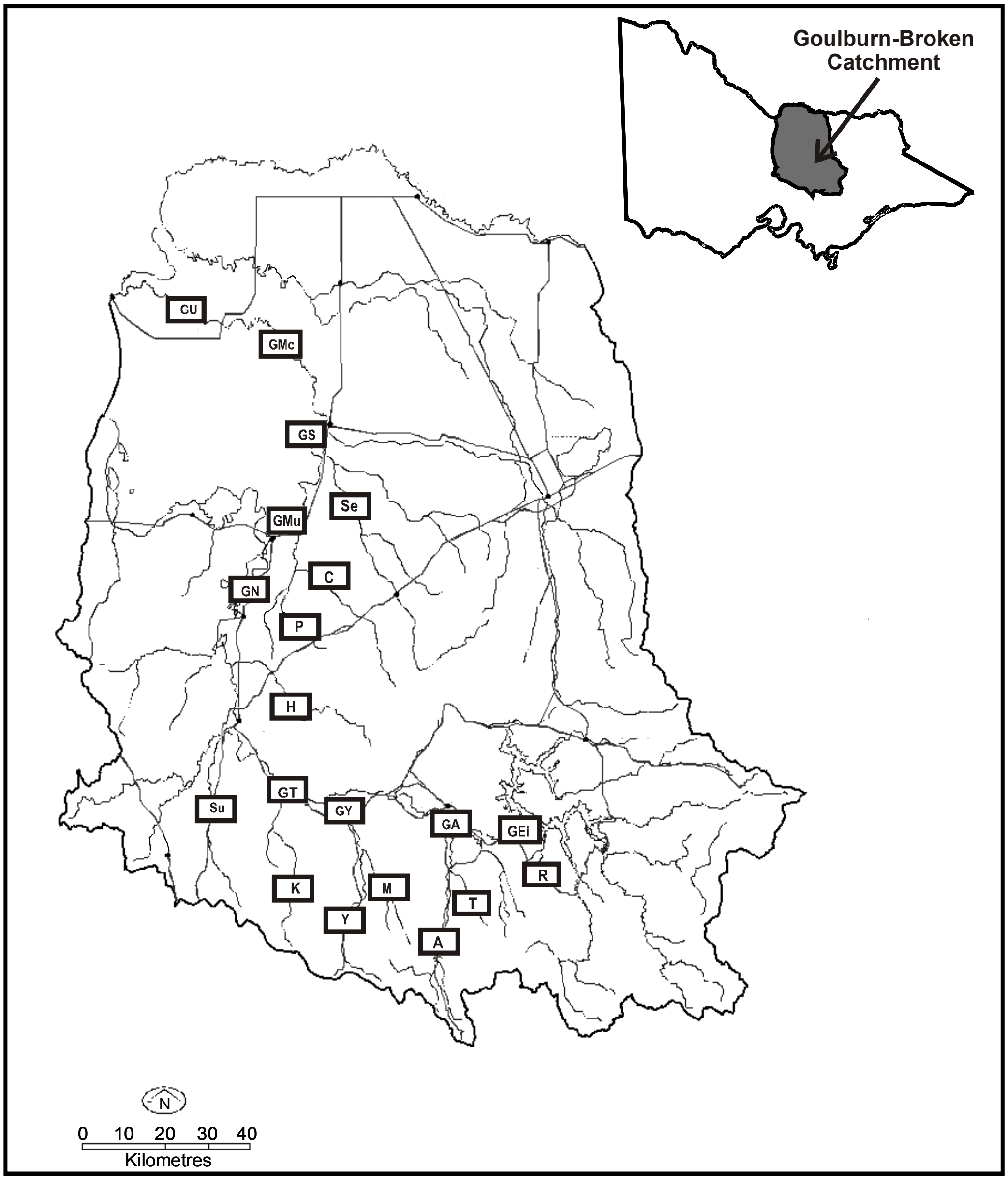


Figure 1: Map of the Goulburn Catchment (see table 1 for definition of site symbols).

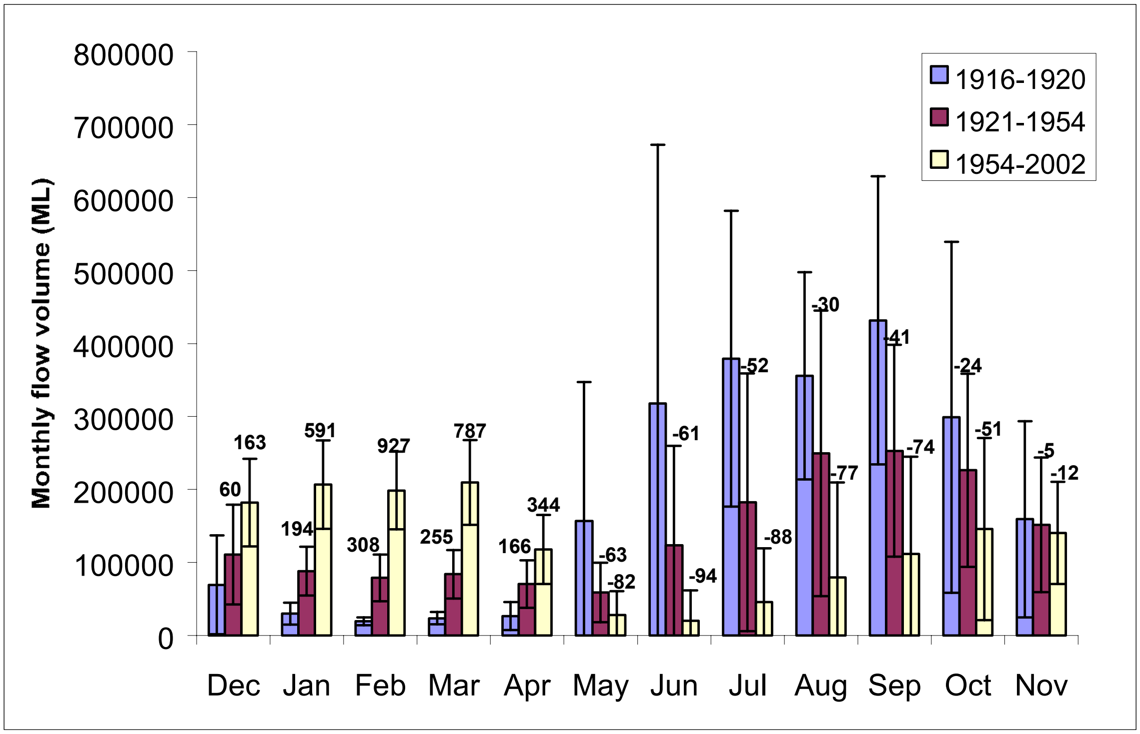
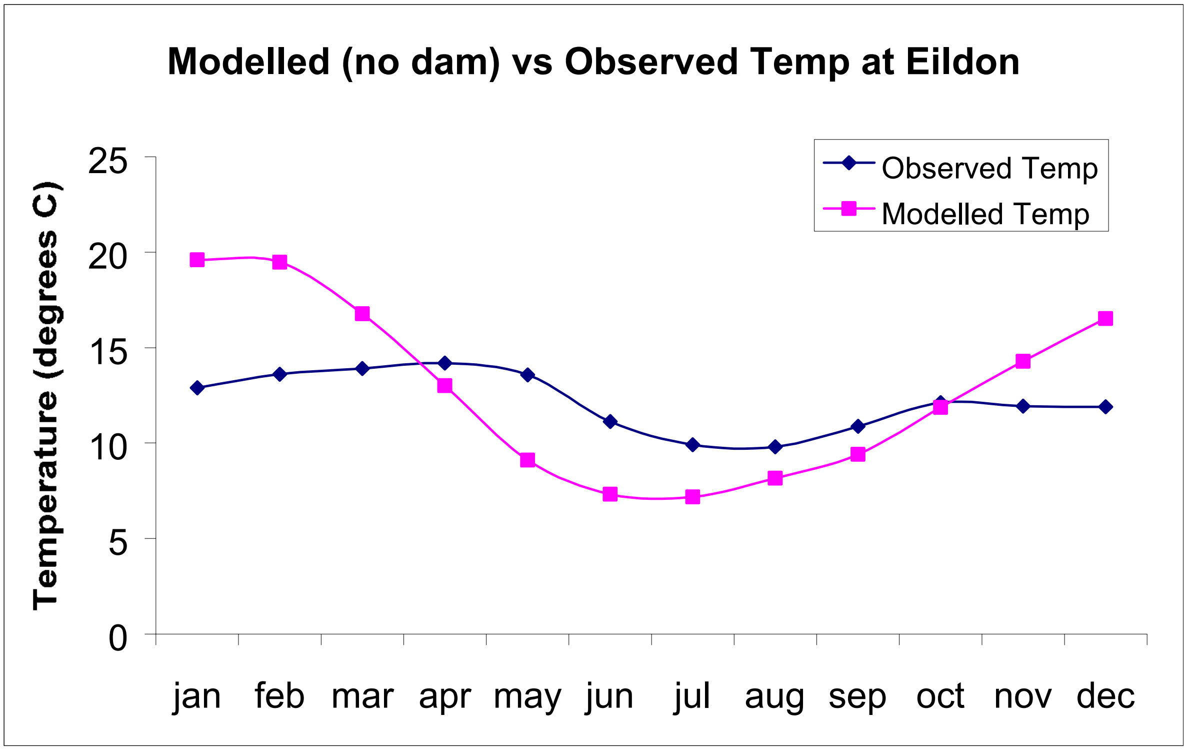


Figure 2: Mean (SD) monthly pre-regulation and post regulation flows for Sugarloaf Dam (1921 - 1954) and Eildon Dam (1954 - 2002). Figures above bars represent the percentage change of means between pre-regulation and post-regulation flows.



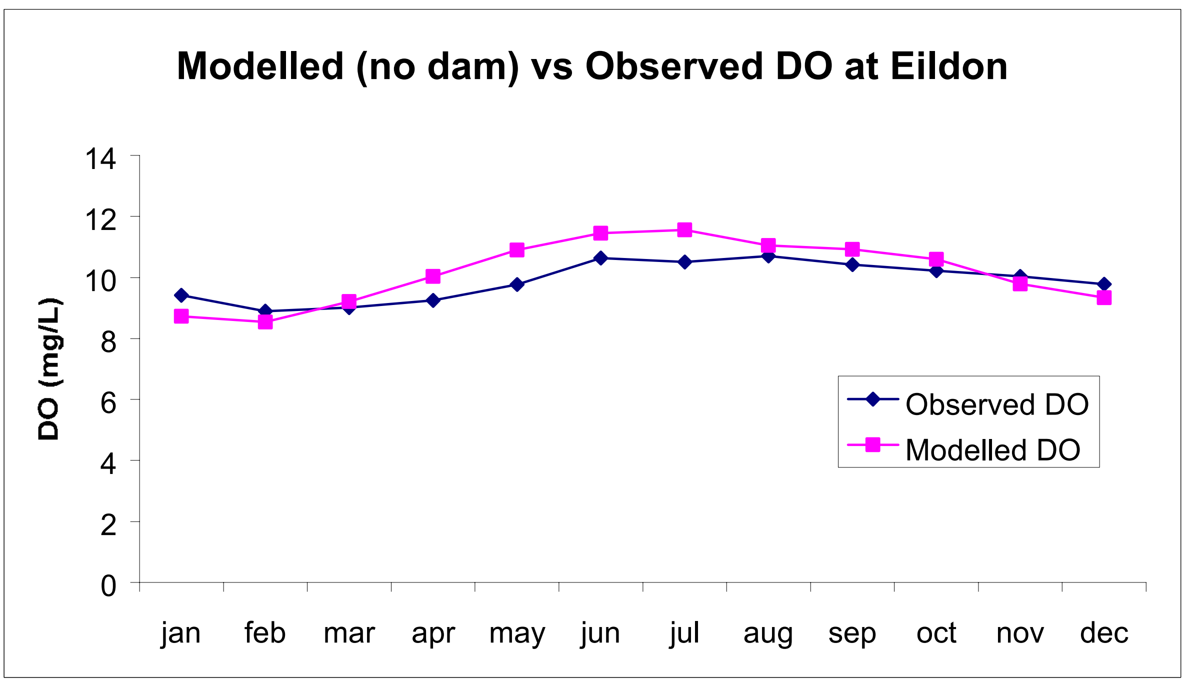


Figure 3: Modelled (assuming no dam at Eildon) and observed (a) temperature and (b) dissolved oxygen at Eildon. Models were created according to the methods of Gippel *et al.* (1993).

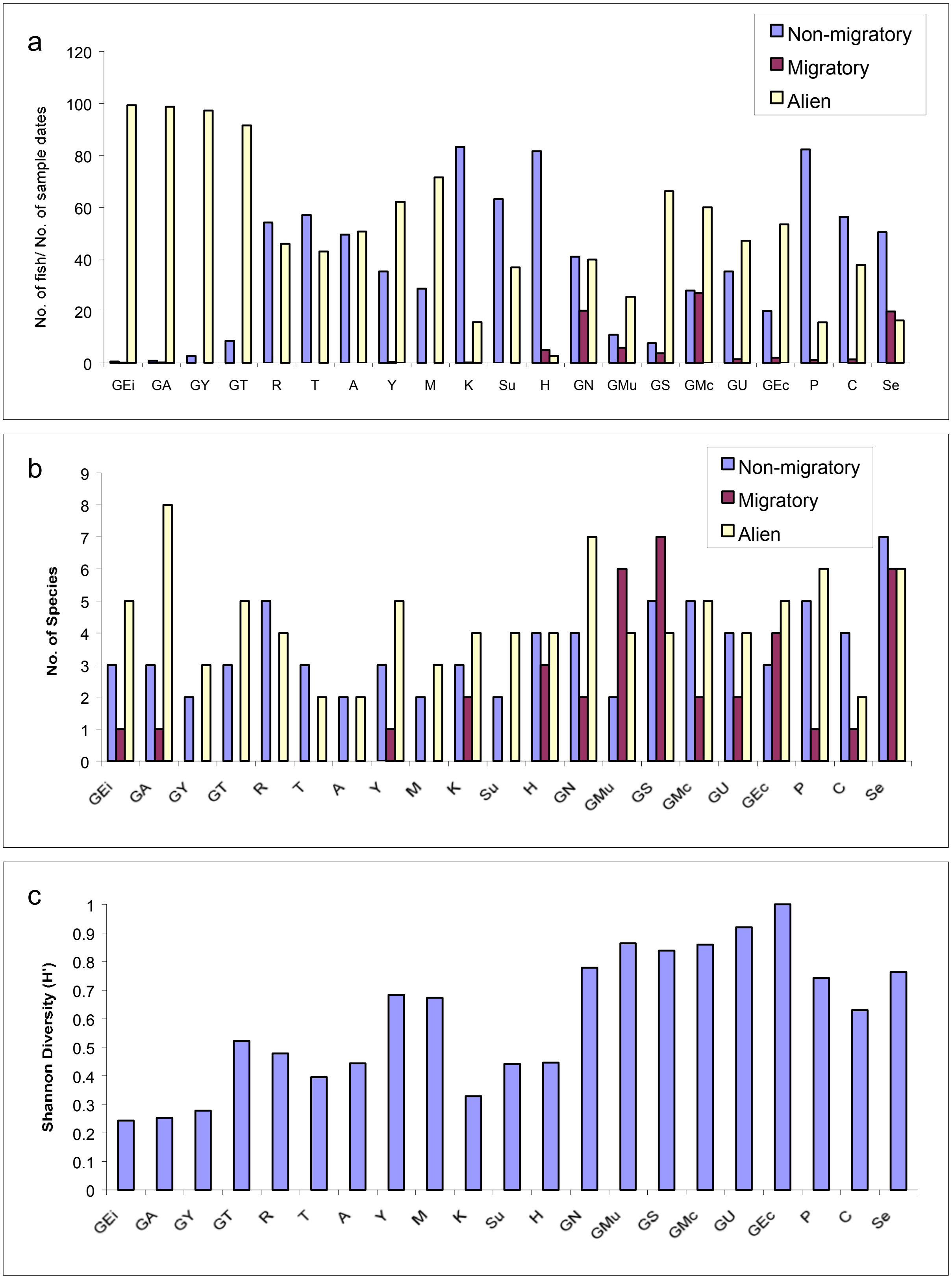


Figure 4: Fish community variables at each site of interest in the Goulburn Catchment: (a) Relative abundance of fish species, (b) Number of fish species, and (c) Shannon Diversity (H').

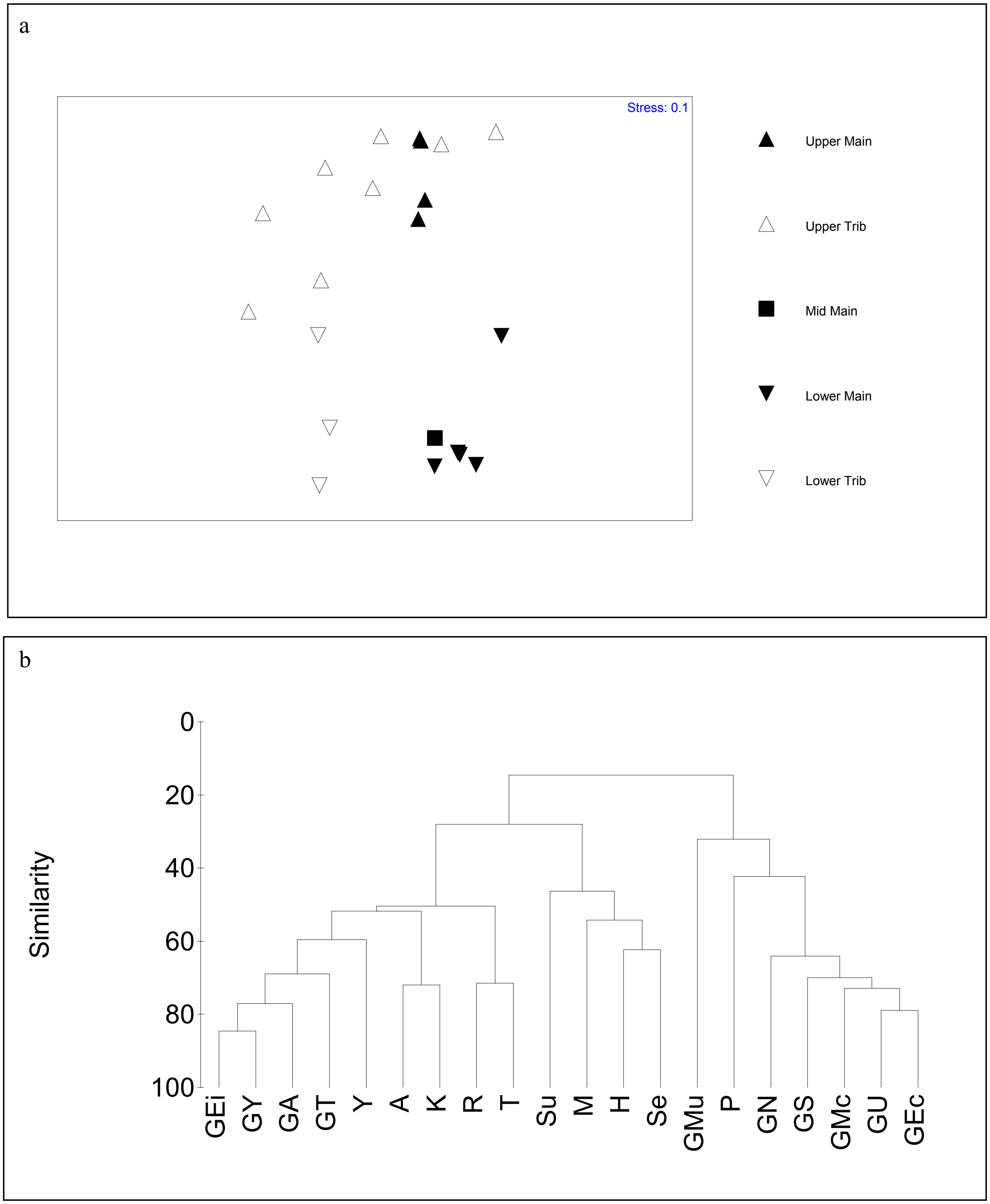


Figure 5: (a) MDS ordination of species from sites showing relationships between the abundances of all fish in the Goulburn Catchment; (b) Cluster analysis for abundances of all fish in the Goulburn Catchment.

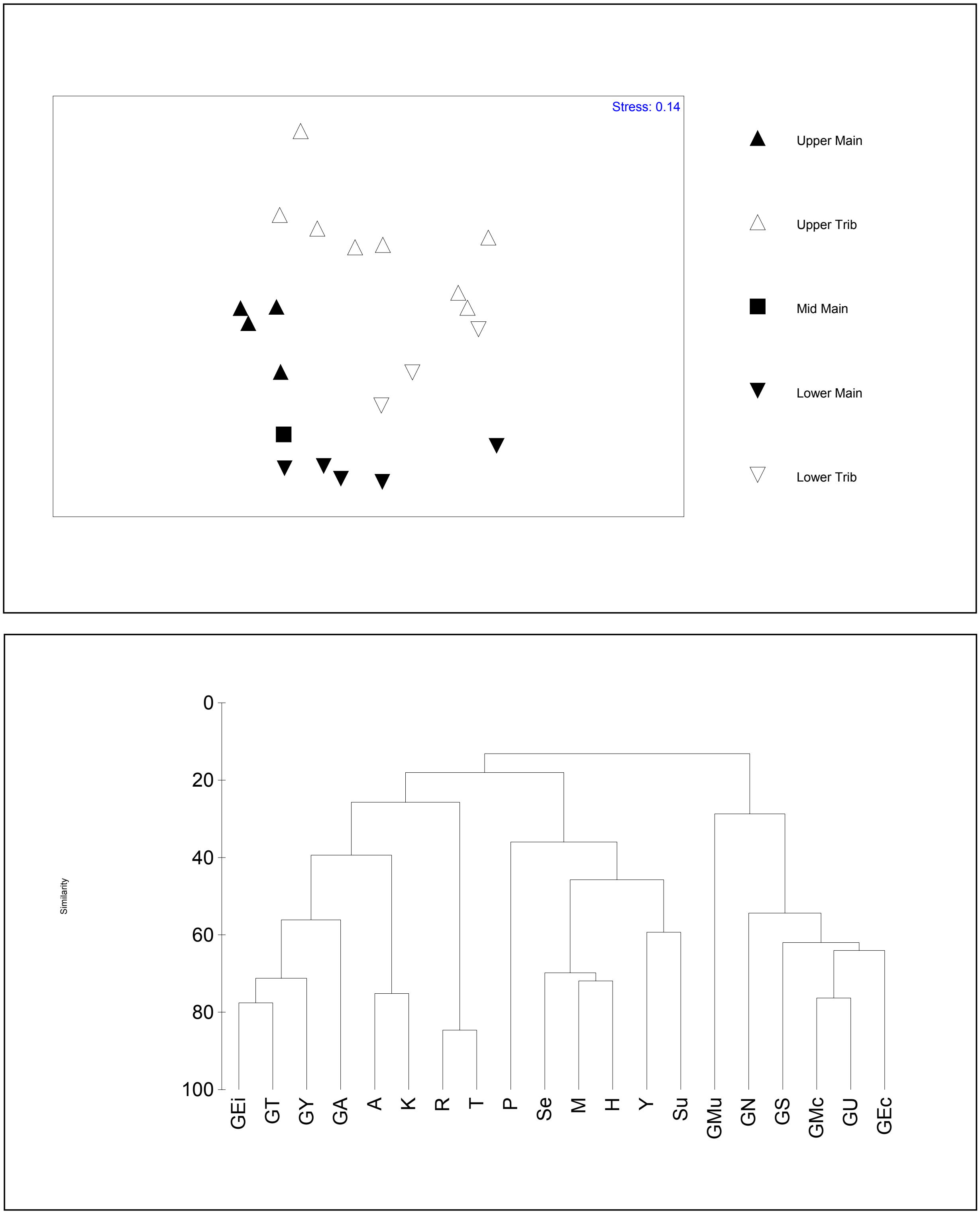


Figure 6: (a) MDS ordination of species from sites showing relationships between the abundances of native fish in the Goulburn Catchment; (b) Cluster analysis for abundances of native fish in the Goulburn Catchment.

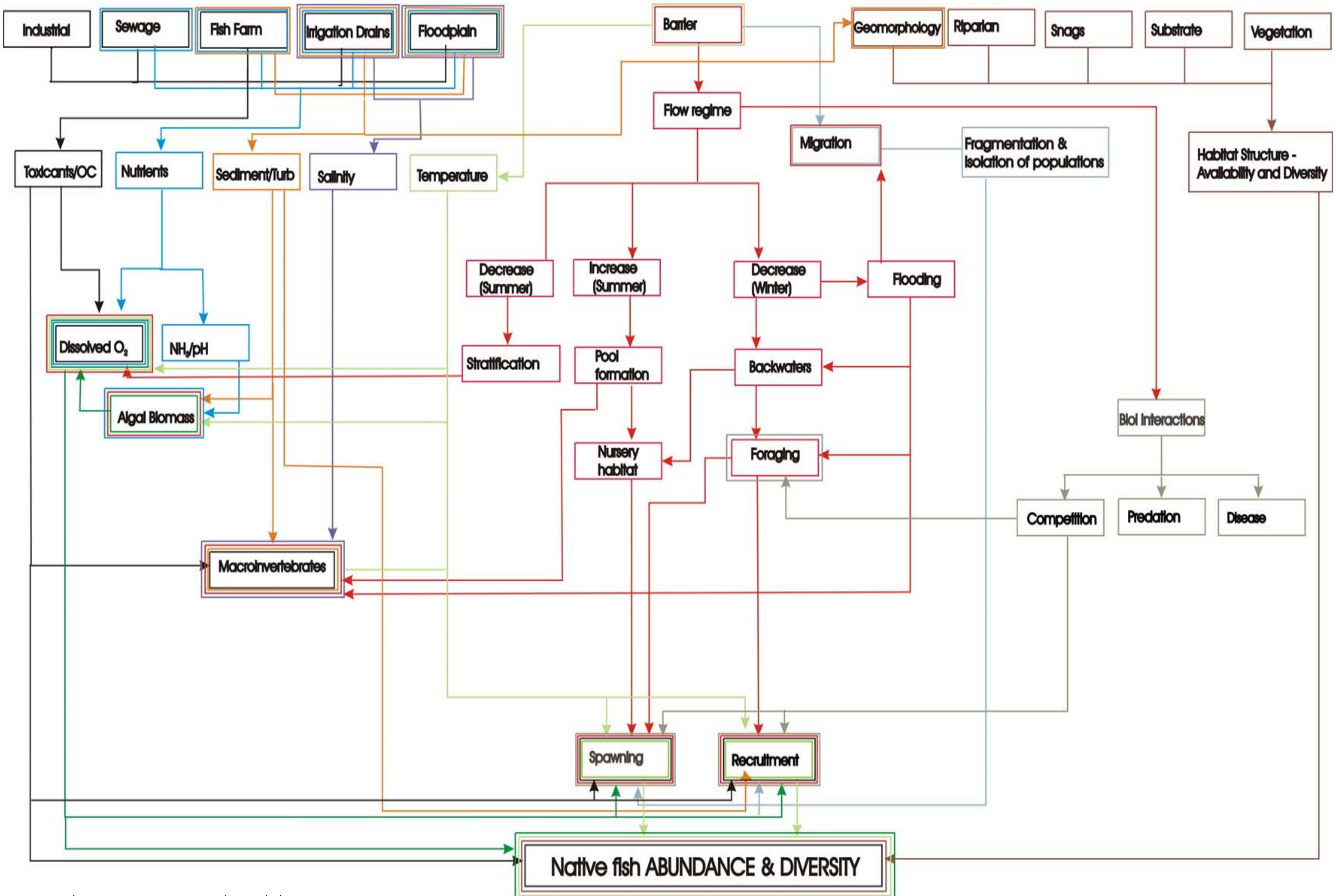


Figure 7: Conceptual model

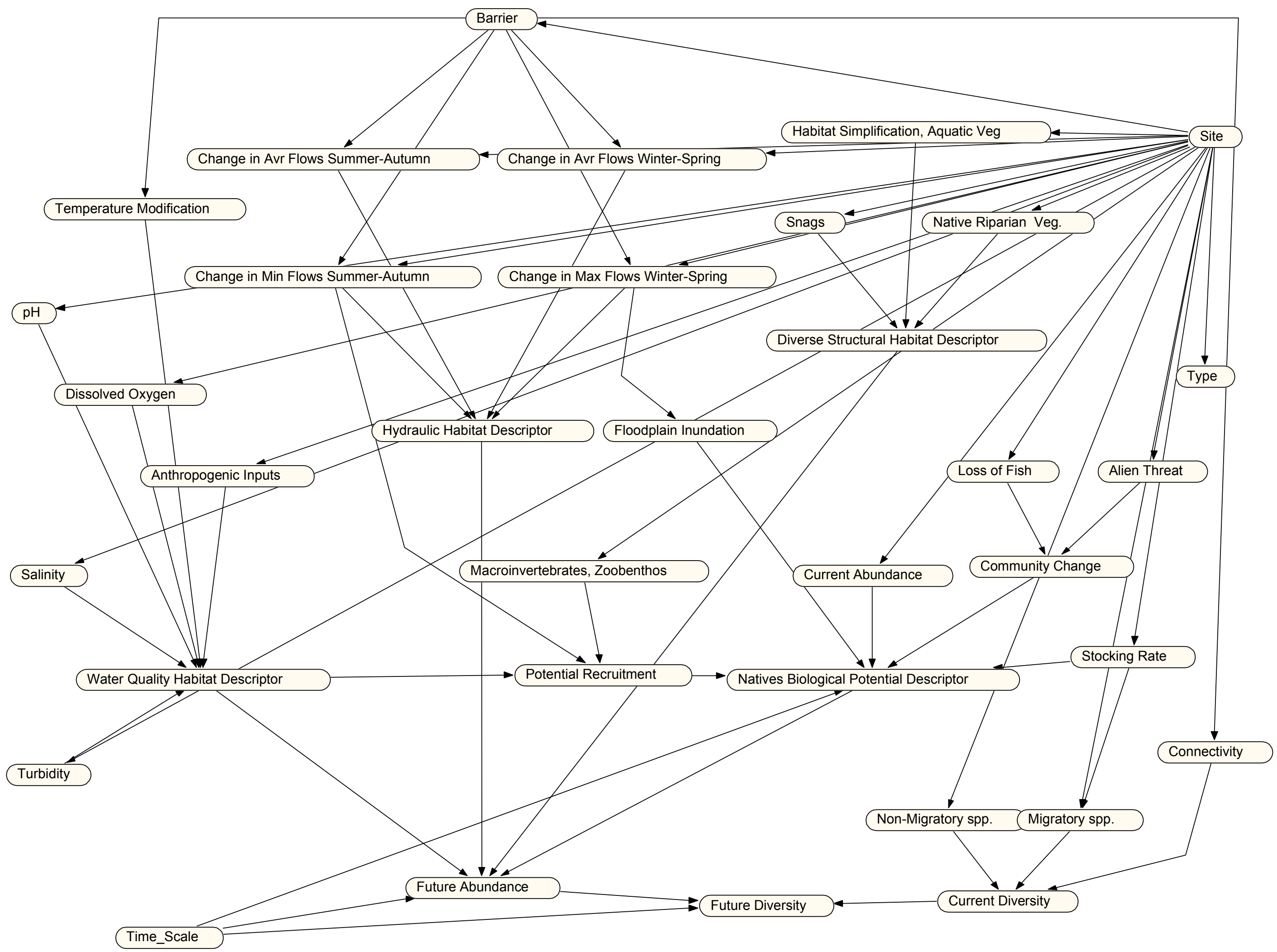


Figure 8: Structure of the BN model

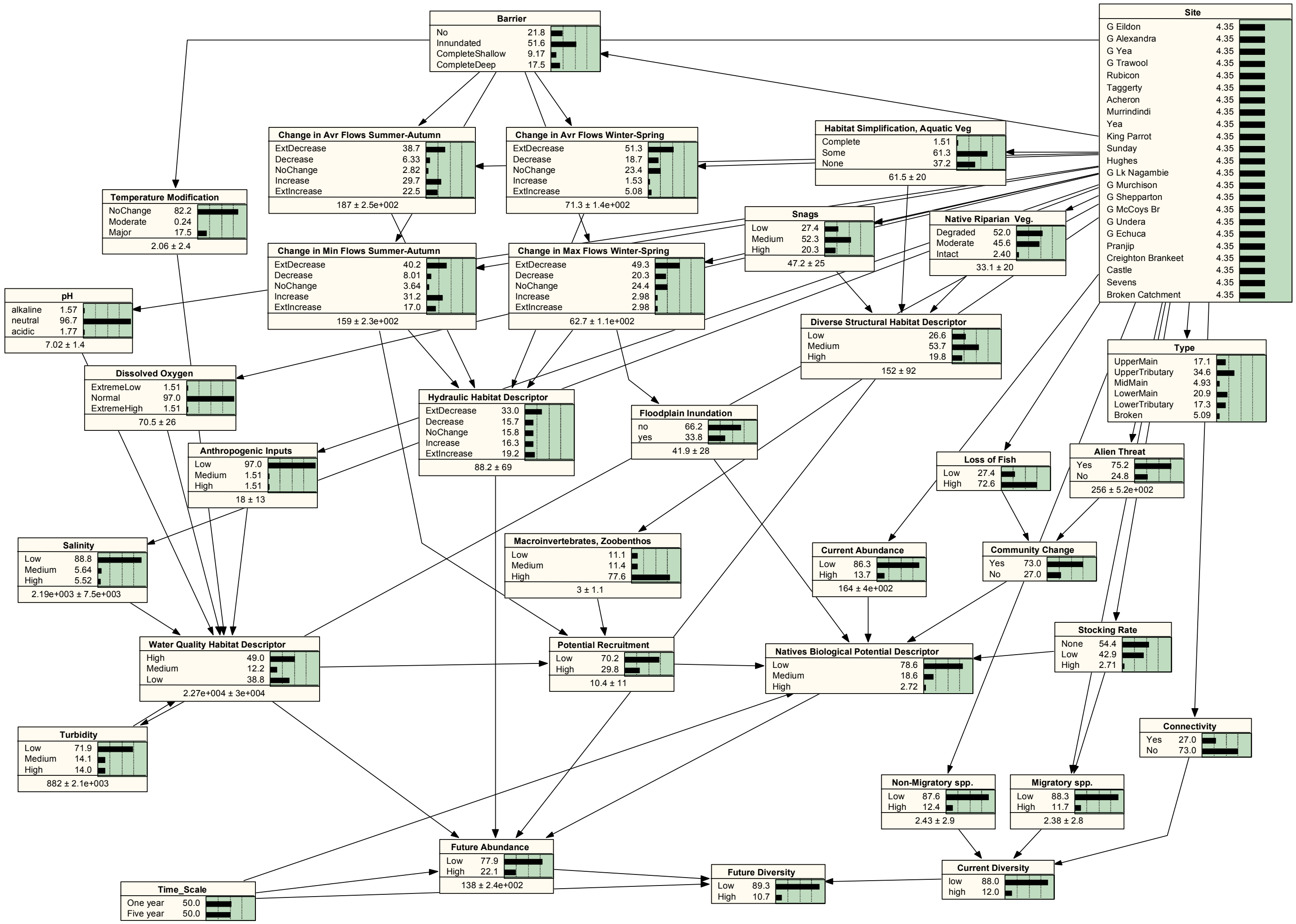


Figure 9: Generic BN model

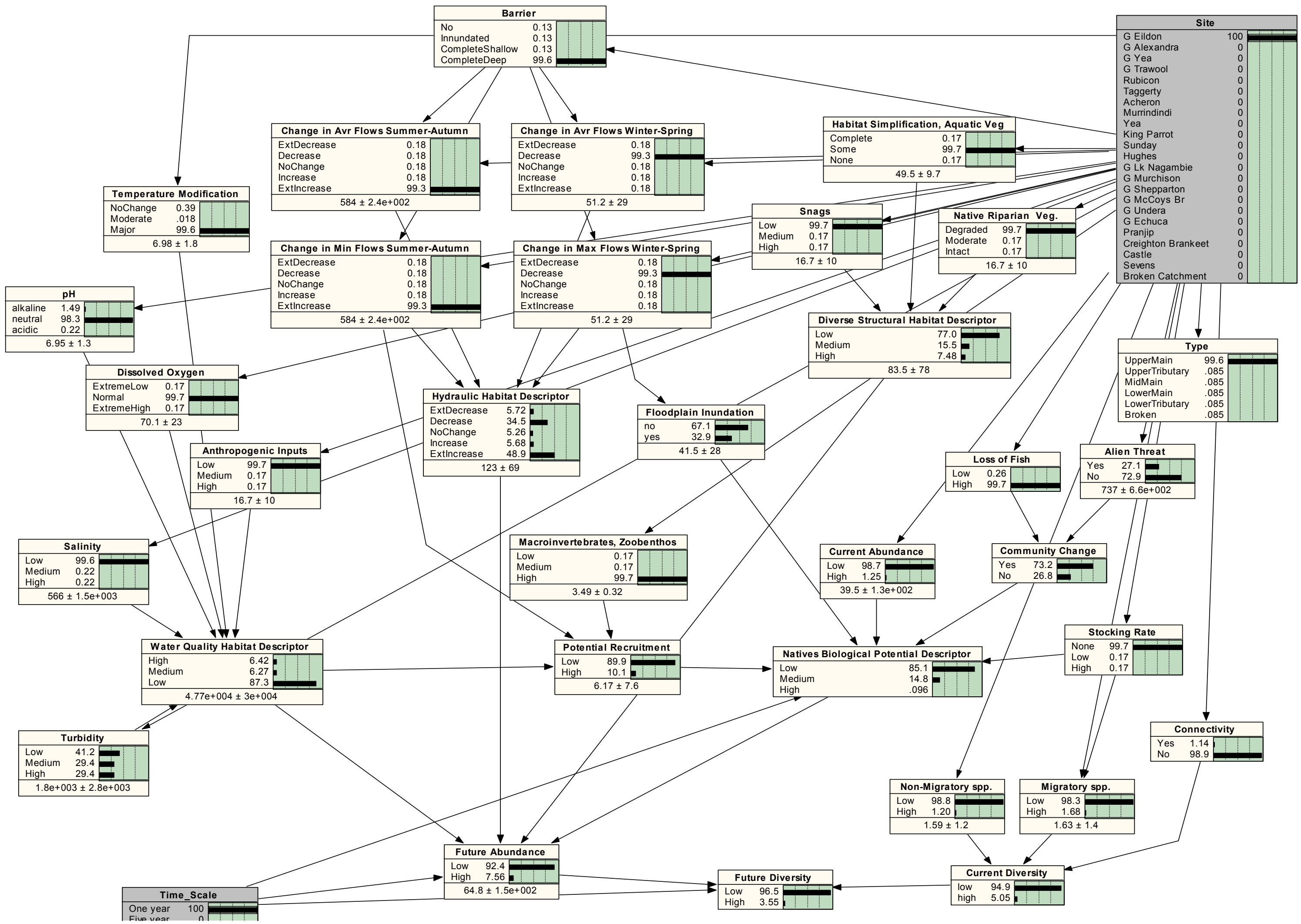


Figure 10: BN model specific for Eildon, with a one-year temporal scale.

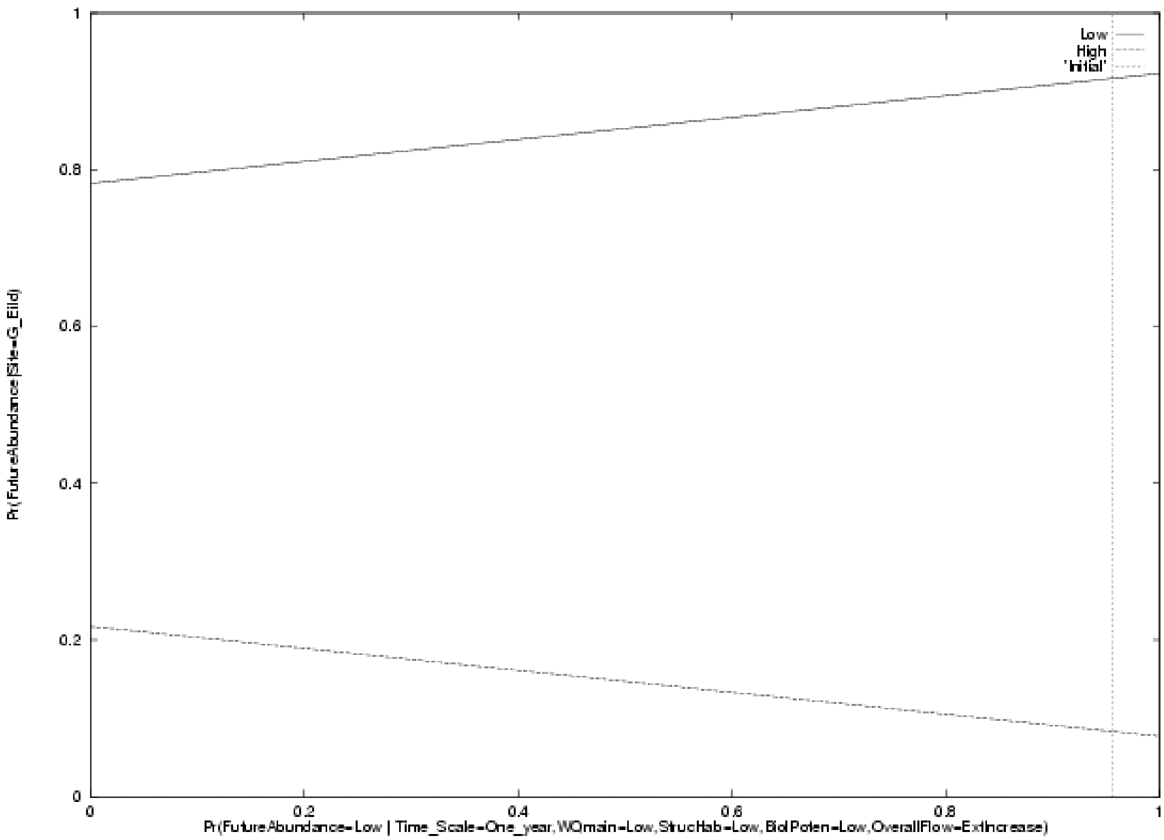
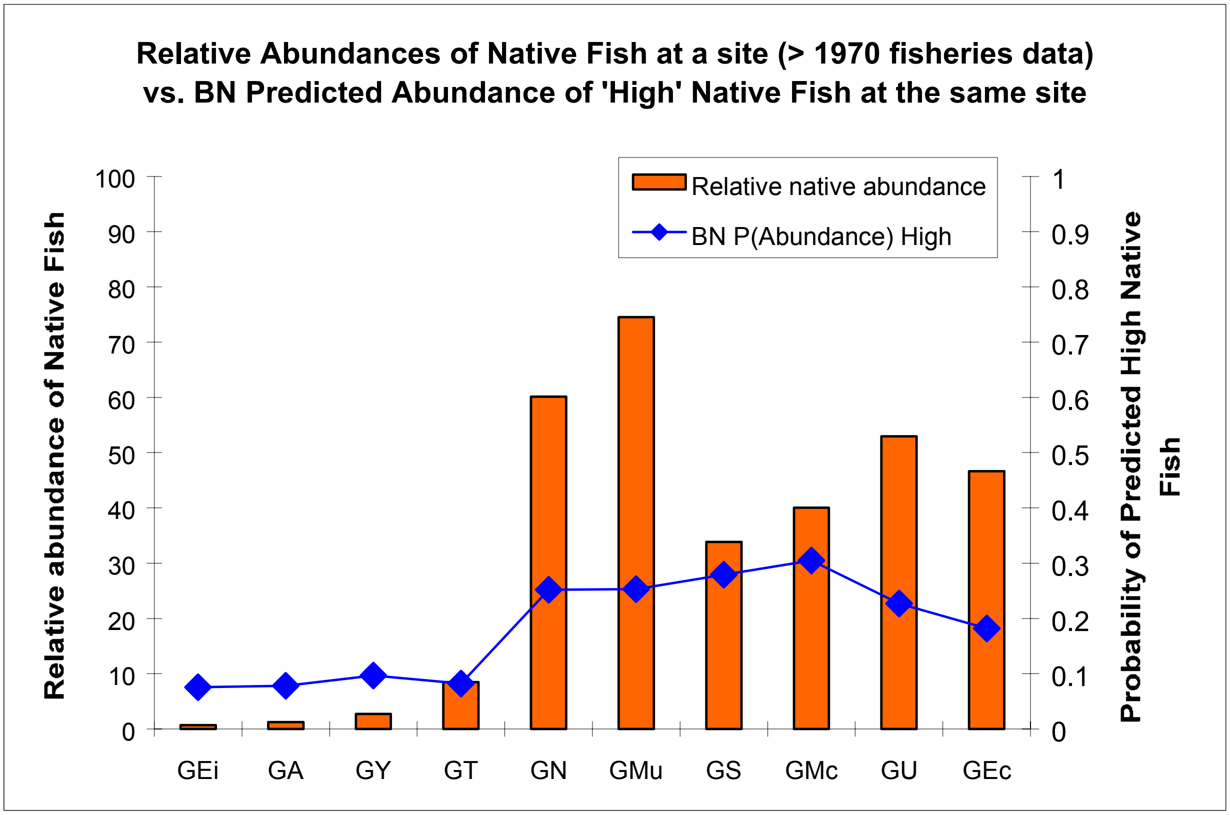


Figure 11: Sensitivity to parameters output showing slope of change for high and low future native fish abundances at Eildon. Conditions represented are the worst-case scenario conditions within the model. The shallow slopes indicate the model robustness to parameter change.



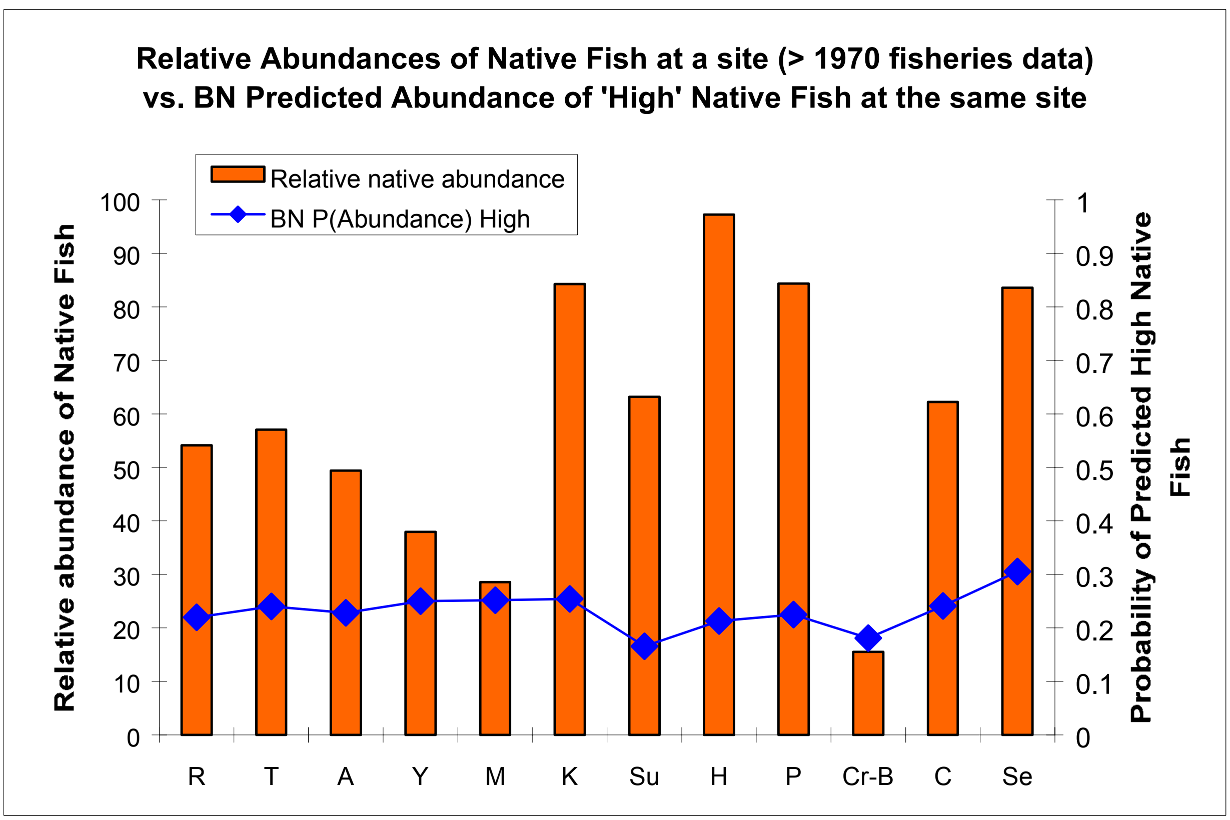
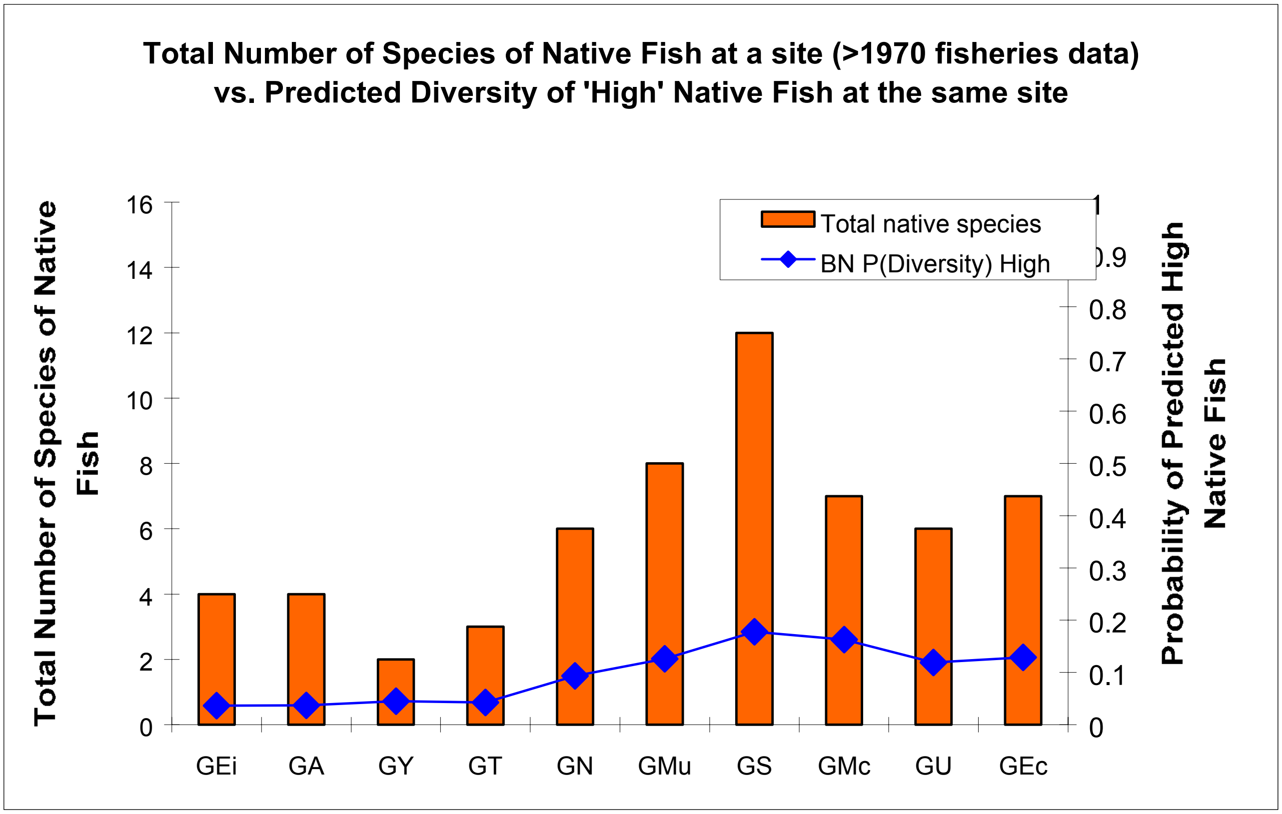


Figure 12: Current abundance data versus BN model output for (a) the Goulburn main channel and (b) Goulburn tributaries.



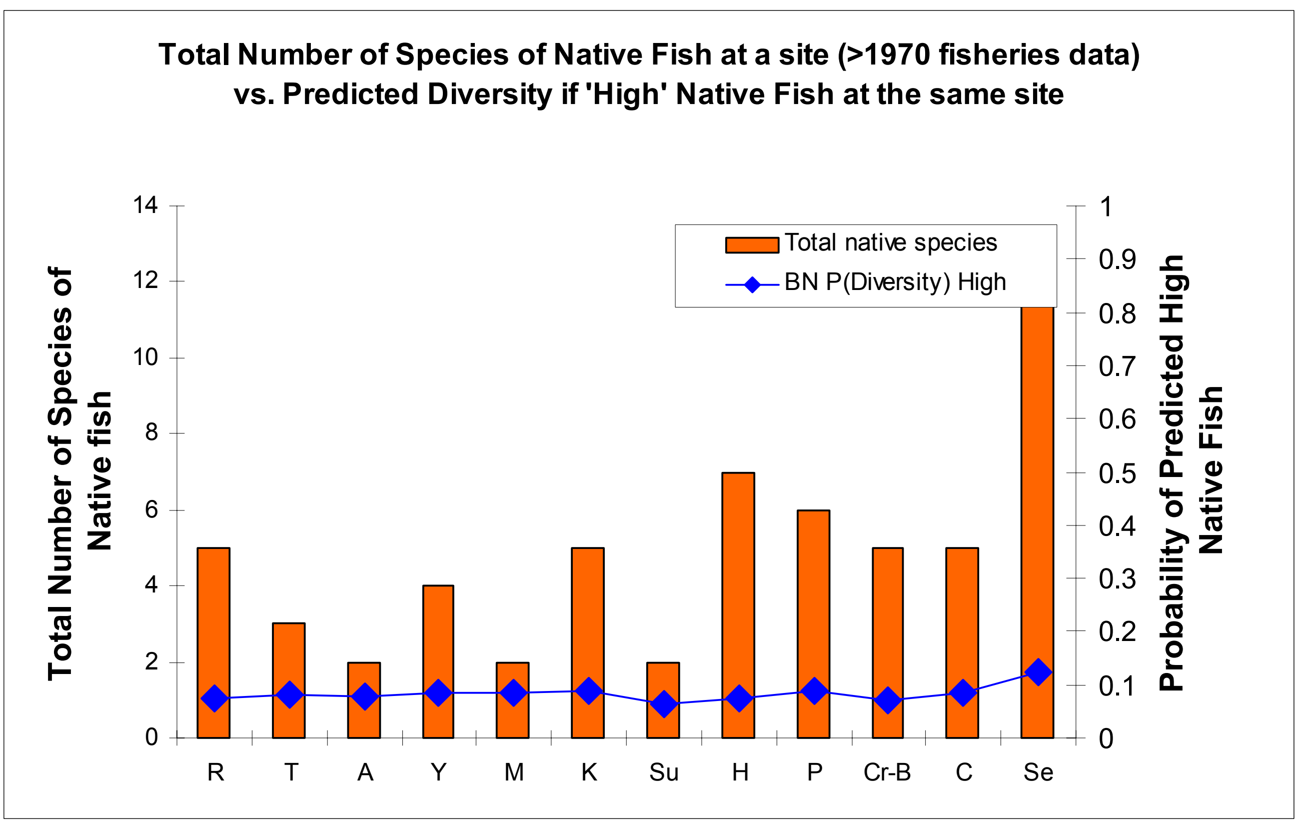


Figure 13: Current diversity data versus BN model output for (a) the Goulburn main channel and (b) Goulburn tributaries.

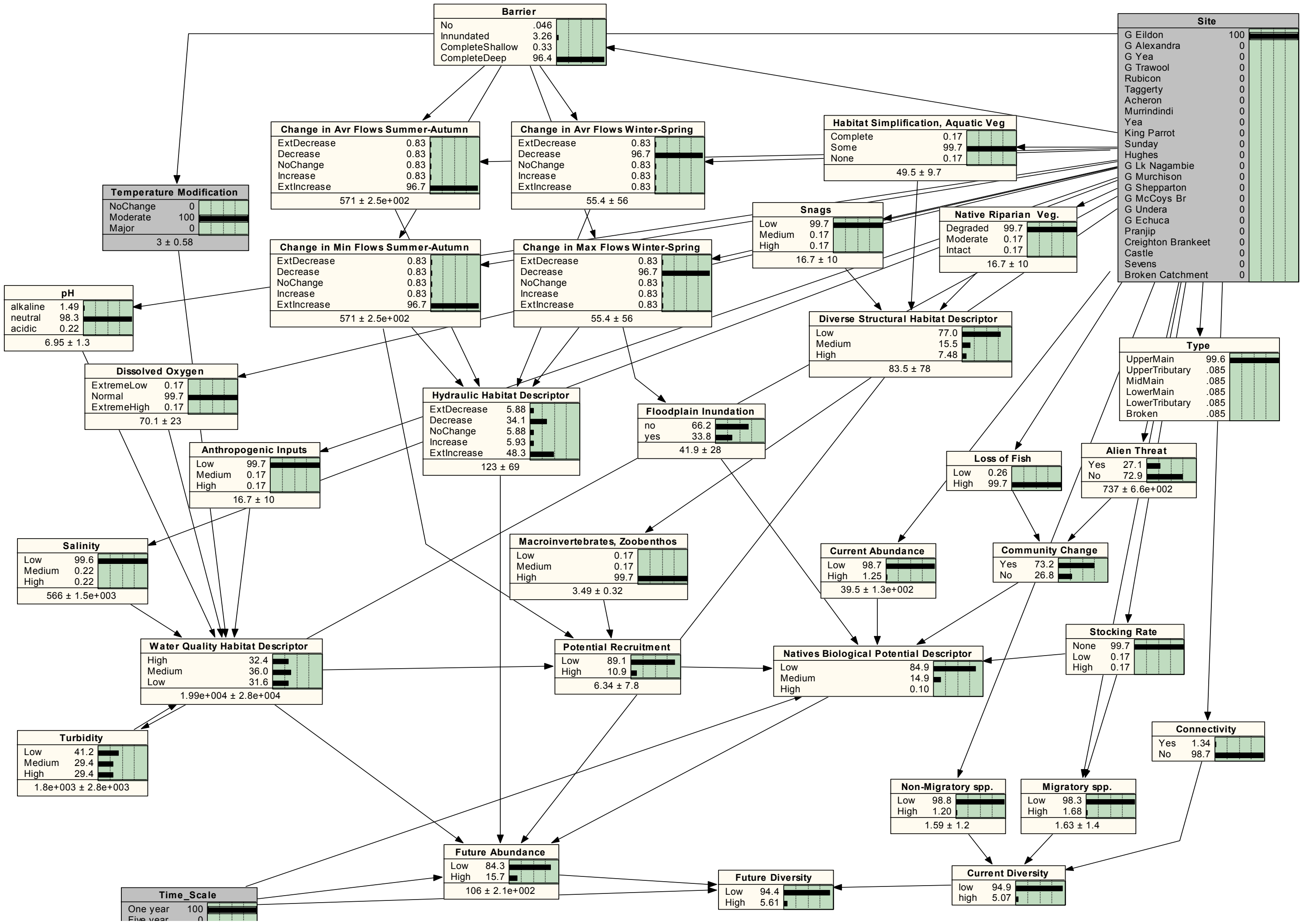


Figure 14: Temperature mitigation at Eildon, with barrier type being retained.

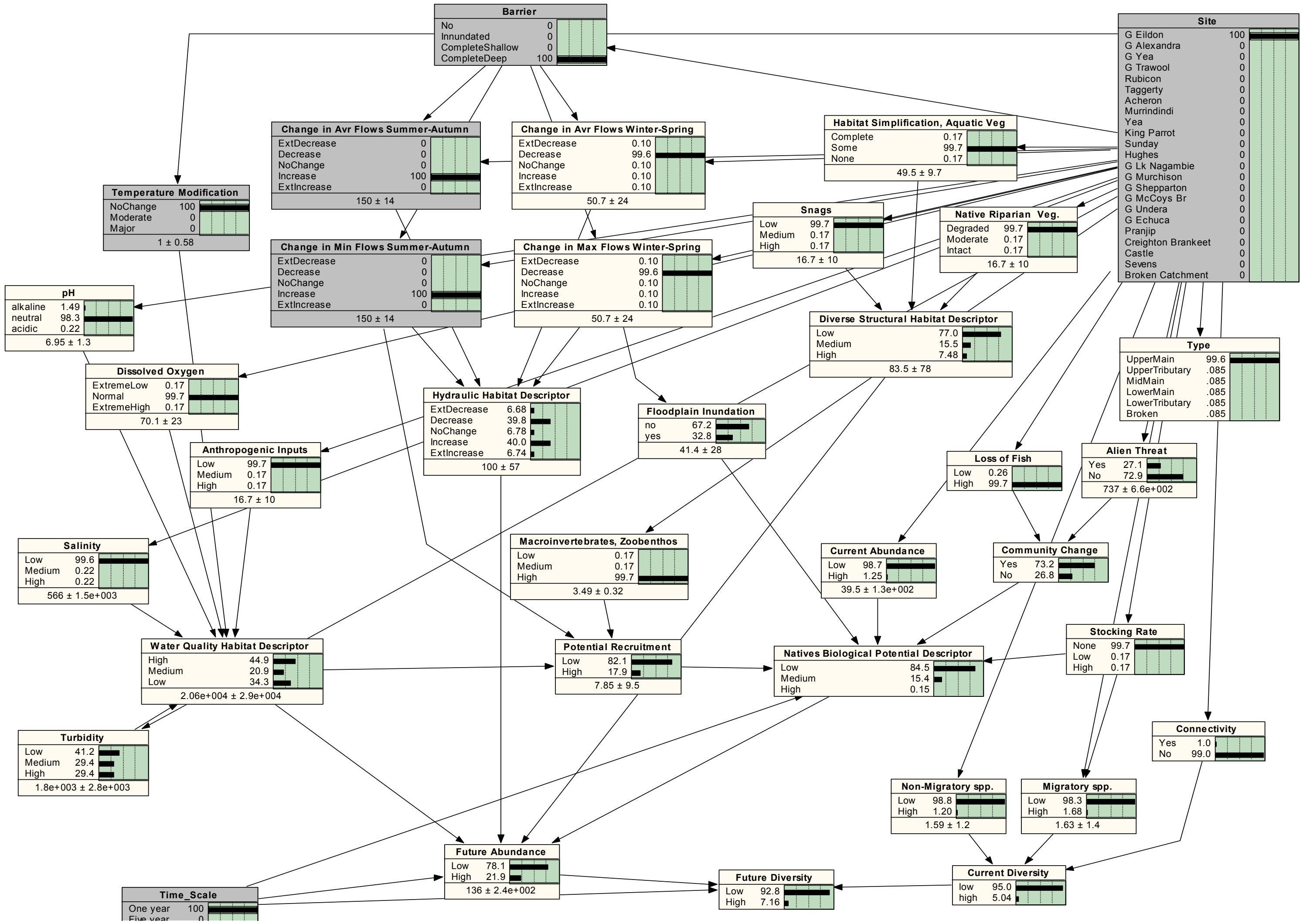


Figure 15: Temperature and moderate flow mitigation at Eildon, with barrier type being retained.

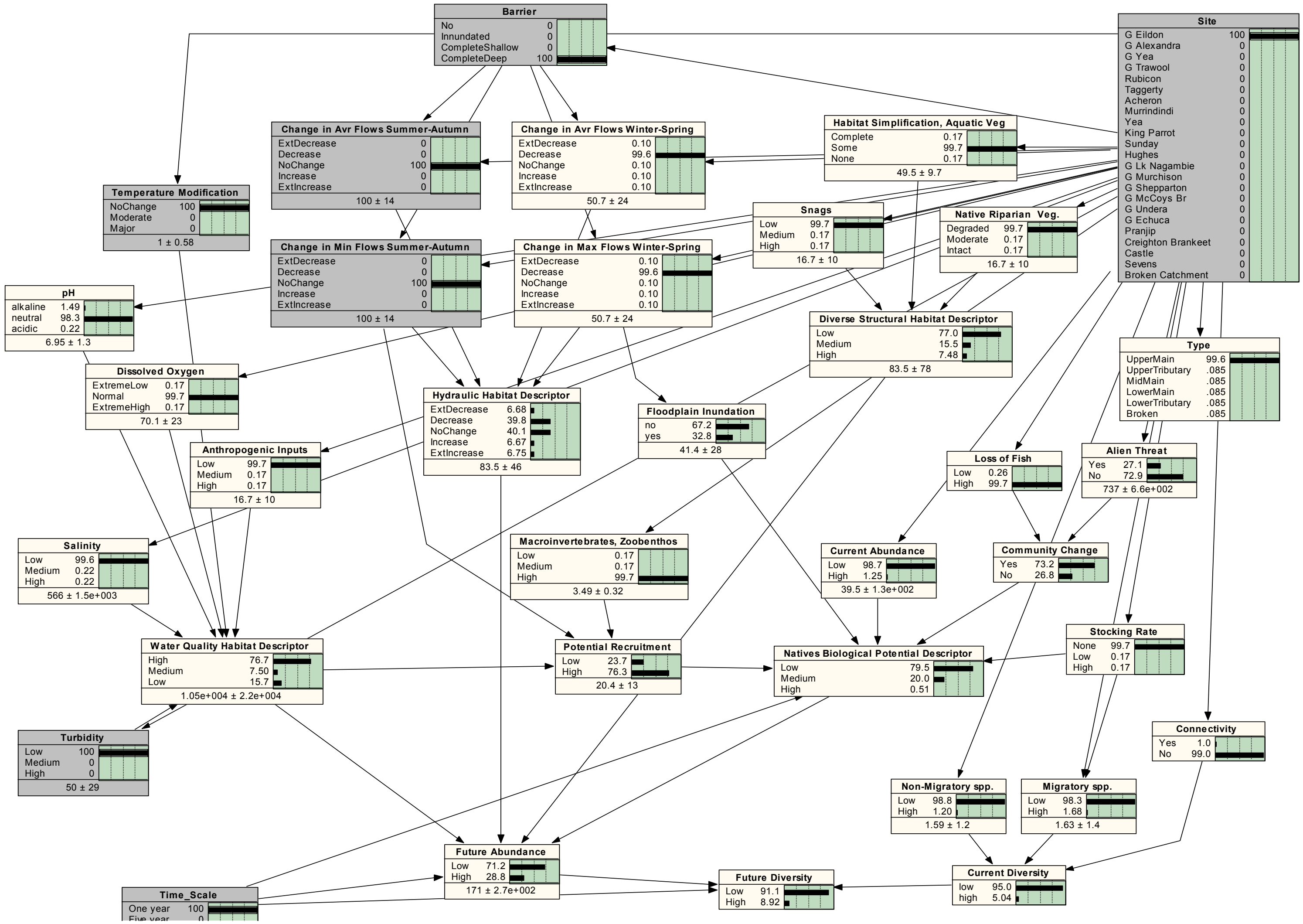


Figure 16: Temperature and flow mitigation at Eildon, with barrier type and low turbidity being retained.

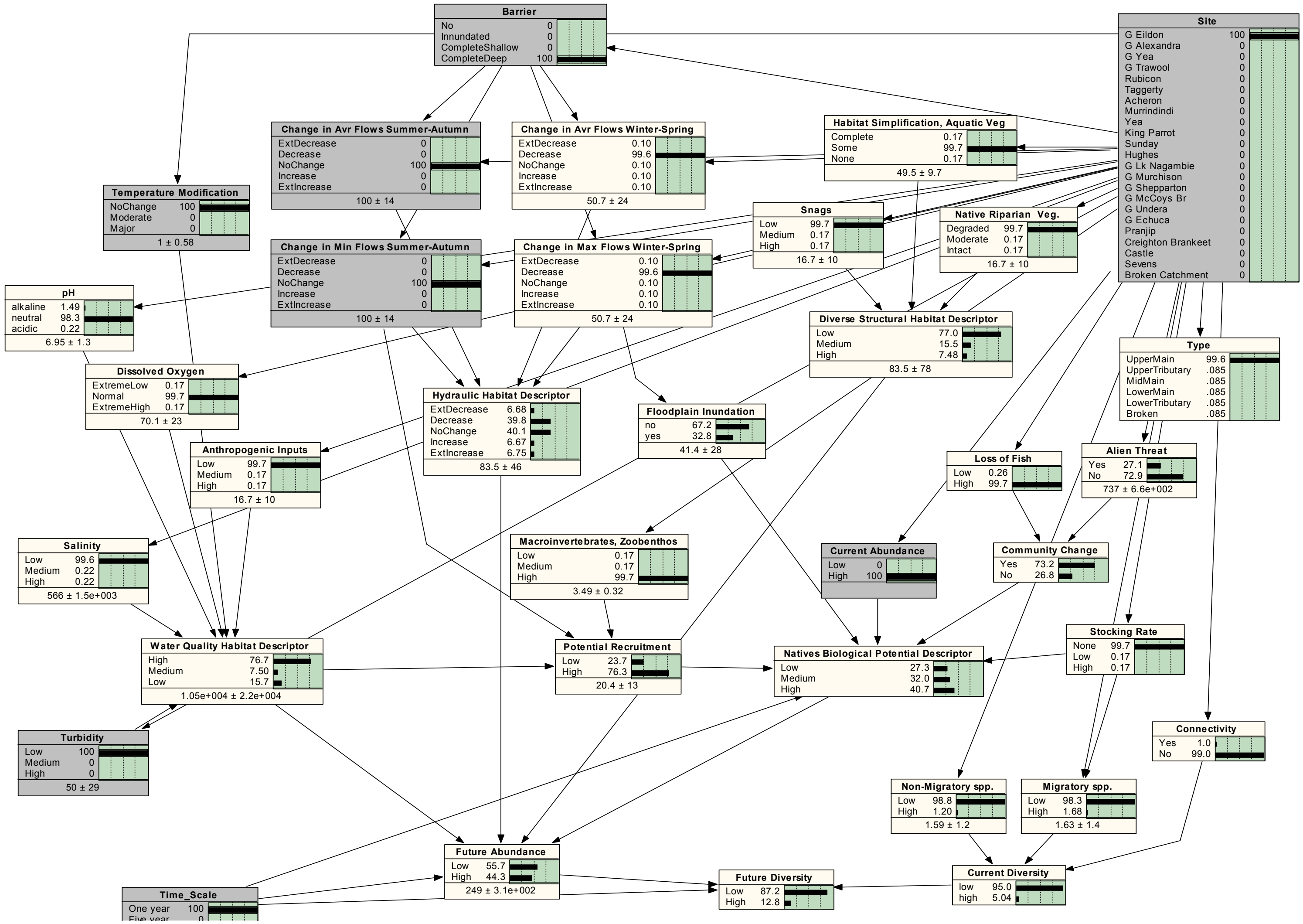


Figure 17: Temperature and flow mitigation at Eildon, with barrier type and low turbidity being retained. Current abundance is high.

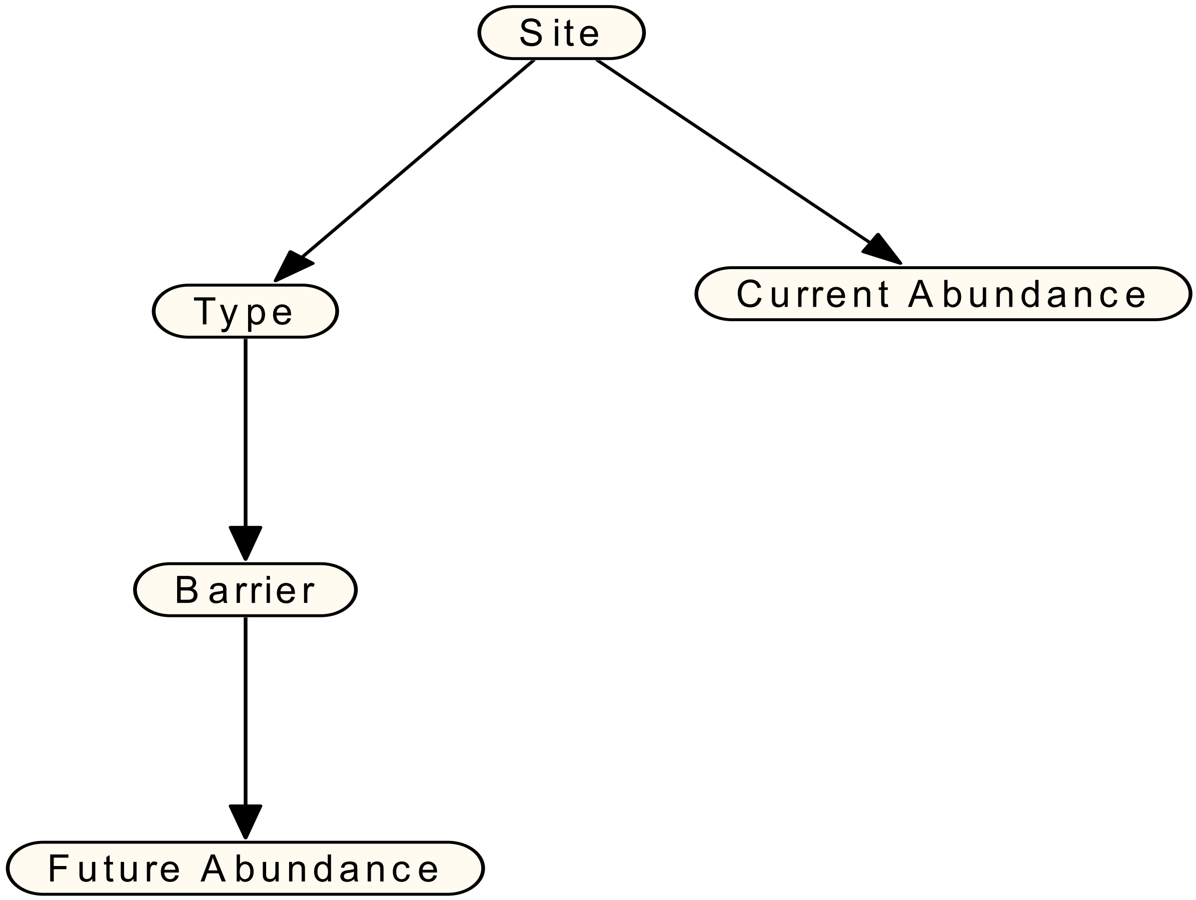


Figure 18: CaMML structure, a data mining technique describing fish communities in the Goulburn Broken Catchment.

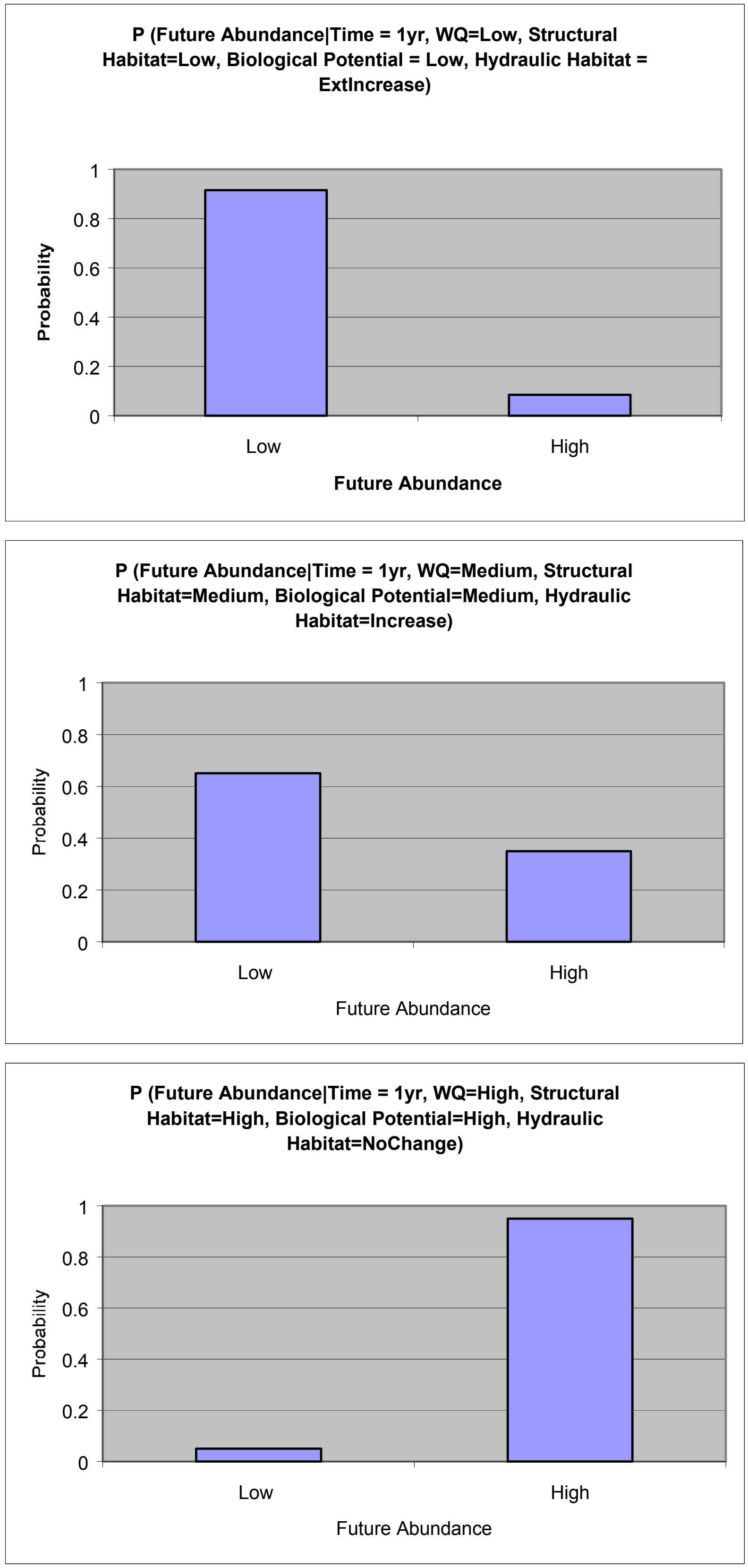


Figure 19: Relationships between risk factors and native fish abundance in BN model.

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APPENDIX 1

Fish communities and habitat changes in the highly modified Goulburn Catchment, Victoria, Australia

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Fish communities and habitat changes in the highly modified Goulburn Catchment, Victoria, Australia

Abstract

Evidence for the decline in native fish communities in the Goulburn Catchment has been based primarily on studies investigating changes to environmental conditions as a result of river regulation. This study aggregates fisheries data from the lowland catchment to spatially compare native fish communities in the catchment. Multivariate analyses demonstrated that distinctly different community compositions are found in different parts of the catchment. Eildon Dam, a deep release reservoir, has drastically altered the hydrology and water quality of the upper Goulburn River, and ordination analyses show that this has created both physical and artificial barriers to movement of native fish into the main channel. Concurrently, fisheries data from the upper main channel show the community is highly divergent compared to the remaining catchment. Further downstream, Goulburn Weir creates a barrier to fish movement between Lake Nagambie and the lower Goulburn Catchment, and alters the natural hydrological regime. SIMPER analyses demonstrate that these stressors have facilitated the establishment of alien species, which dominate fish abundance in the upper and lower main channels. This study emphasises the need to explore alternatives for improving management strategies to rehabilitate fish communities throughout the Goulburn Catchment.

Additional keywords

flow regime, water quality, temperature, regulated river, fish community

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Introduction

Schemes to regulate the flow of rivers have had a major affect on the integrity of riverine ecosystems worldwide. As a means of securing water supplies for human use in the extreme climatic conditions of Australia, many of the rivers in the south eastern corner of the continent have been modified. Today, flow regulation is widely acknowledged as a major cause for the deterioration of Australia's riverine ecosystems (Arthington and Pusey 2003). In response, the need for reform of management of river systems has been recognised at both the State and Federal Government level (COAG 2003).

The Murray-Darling river system, in the south eastern part of Australia, extends across four States and has a long history of regulation. The system has been extensively modified by hydroelectric, irrigation and water transfer schemes in order to satisfy agricultural and urban water supply purposes (Cadwallader 1978). Historically, little attention was paid to the downstream aquatic habitat in the construction and operation of dams (Finlayson *et al.* 1994). As a result, the Murray-Darling River system has experienced extensive degradation, with native aquatic fauna declining in abundance and diversity (Cadwallader 1978).

Study System

The largest tributary of the Murray-Darling river system in the State of Victoria is the Goulburn River (Figure 1). The lowland portion of the Goulburn River has a long history of river regulation, primarily for the purpose of irrigation. The headwaters of the Goulburn River were first dammed in 1921 by Sugarloaf Dam (capacity of

377,400 ML). In 1955 this was replaced by the larger Eildon Dam (capacity of 3,390,100 ML), forming Lake Eildon. Water released from Lake Eildon is delivered 218 km downstream to the major offtake, Goulburn Weir (capacity of 25,000 ML) (Finlayson *et al.* 1994). Goulburn Weir was constructed in 1889 forming Lake Nagambie. From Goulburn Weir, outflows are to the lower Goulburn River and to irrigation areas via three large channels (Cottingham *et al.* 2003).

Altitudes of the lowland study area range from between 200 and 300 m above sea level in the Eildon area, to 0 and 100 m above sea level in the Echuca area. Fifteen *(correct?)* tributaries enter the 436 km lowland stretch of the Goulburn River, extending from Eildon Dam to its confluence with the Murray River (Gippel and Finlayson 1993). The majority of these tributaries have some form of barrier that can be inundated during higher flows in a typical year (http://www.vicwaterdata.net/; accessed January 2004). Barriers can include small farm dams, culverts, or other structures that may prevent migration of fish.

As a result of regulation, the hydrological regime of the lowland Goulburn River has been dramatically altered. Below Eildon Dam, the mean annual flow in the Goulburn River has not changed (Nathan 1992) but the mean monthly flows have been altered substantially with peak flows now occurring during summer and autumn rather than winter and spring (Gippel and Finlayson. 1993) (Figure 2). Flow maxima have also been reduced, resulting in fewer overbank flows and flooding of wetlands (Gippel and Finlayson. 1993; Finlayson *et al.* 1994). Finlayson *et al.* (1994) reported that wetlands that once flooded annually now flood only three years in ten. Hydrological changes decline downstream, with little post-dam change 200 km downstream as a result of flood runoff from tributaries (Erskine 1996).

At Lake Nagambie (Figure 1), water extraction has reduced the mean annual flow to the remaining section of the Goulburn River (Nathan 1992) but the natural seasonal flow pattern has been maintained. In the tributaries, the hydrological regime at the majority of sites remains largely intact.

In addition to changes in hydrology, Lake Eildon has had a major effect on water quality, primarily as a result of alterations in water temperature downstream of the dam structure. Lake Eildon is thermally stratified during summer and as water is released from below the thermocline, at a depth of 52 m below full supply level, water temperatures are lower than would naturally occur (Erskine 1996). As there are no pre-dam water quality data, Gippel and Finlayson (1993) modelled temperature parameters, assuming no dam. Model data demonstrates that water temperatures below Eildon Dam have been reduced by up to 7 ^{o}C in summer (Figure 3). Altered thermal conditions extend 138 km downstream to Seymour (Gippel and Finlayson 1993).

Only minor changes in dissolved oxygen were calculated, despite water released from Lake Eildon originating from deep within the reservoir (Gippel and Finlayson 1993). In the lower sections of the Goulburn River, water quality is reduced due to increased turbidity, particularly downstream of the Broken River confluence just upstream of Shepparton (Gippel and Finlayson 1993), and increased nutrient concentrations from urban sources and intensive agriculture (State of Victoria 1989). High sediment loads in the lowermost portions of the river have resulted in some habitat simplification (Gippel and Finlayson 1993). In the tributaries of the catchment, water quality varies with high turbidity and nutrients affecting certain areas.

Irrigation activities in the Goulburn Catchment have been implicated in causing a decline in the range and abundance of native fish (Cadwallader 1978). Dams and other barriers have played a major role in reducing the distribution and diversity of fish in Australia (Cadwallader 1978; Gehrke and Harris 2001; Gehrke *et al.* 2002), particularly as a result of changes to flow and thermal regimes. Many native fish species require specific minimum water temperatures and flows for reproductive processes (Cadwallader 1978). Cadwallader (1978) hypothesised that as a result of regulation of rivers, the trigger mechanisms for spawning and recruitment have been removed, and the prevention of migration by barriers has lead to local extinctions. Fishways and fish ladders allow for movement of fish upstream, but there are no such fishways located on the Goulburn River, and only few fishways in tributaries.

Much of the riparian vegetation and woody debris along the Goulburn main channel and tributaries has been removed or is dominated by willows (*Salix* spp.), an introduced plant species. Riparian zones act as an interface between terrestrial and aquatic systems, regulating the transfer of energy and material between systems, as well as transmission of solar energy into the system (Pusey and Arthington, 2003). Riparian vegetation also has an important role in acting as a source for woody debris, which forms an important component of fish habitat and can prevent over exploitation of biota (Koehn and O'Connor 1990).

Aside from the physical changes in the Goulburn as a result of river regulation, introduction of alien species has also been hypothesised as contributing to the decline in native fish (DNRE 2000). Fish of the family Salmonidae were introduced in Australia in the late 1800's as a recreational species (Arthington and McKenzie

1997). Brown trout, rainbow trout, and Atlantic salmon are still stocked at sites above Lake Nagambie, and the Acheron River is considered to have a self-sustaining brown trout population (DNRE 2000). Introduced salmonids are able to survive downstream of Eildon Dam throughout the year due to the altered thermal regime (Cadwallader 1978). Other alien species are now established throughout the Goulburn River and tributaries, including common carp, goldfish, gambusia and redfin perch. These species are considered habitat generalists, and are known to thrive in disturbed habitats (Stanford *et al.* 1966), often replacing the lost native fauna.

Although studies have interpreted the changes to environmental condition in the Goulburn Catchment as being detrimental to native fish (Gippel and Finlayson 1993; Erskine 1996), as yet no study has examined fisheries data to assess community change. This paper aims to compare fish communities spatially at sites of interest along the Goulburn River main channel and its tributaries, using multivariate statistics and ordination techniques. Sites selected for study are each influenced by a different set of environmental stressors. By characterising fish communities, it is anticipated that a greater understanding of the influences of these stressors on communities will be achieved.

Methods

Description of Sites

The four sites selected for analysis in the upper region of the lowland main channel of the Goulburn River were Eildon (GEi), Alexandra (GA), Yea (GY) and Trawool (GT). The eight upper tributaries were the Rubicon (R), Taggerty (T), Acheron (A), Murrindindi (M) and Yea Rivers (Y), and King Parrot (K), Sunday (Su) and Hughes (H) Creeks. The usage of the term 'upper' for these sites is relevant to this study only.

Lake Nagambie (GN) is the only site representing the mid section of the Goulburn River main channel. The lentic environmental characteristics of Lake Nagambie are distinct from those of the lotic environments of the Goulburn main channel and its tributaries.

The five main channel sites selected below the Goulburn Weir were Murchison (GMu), Shepparton (GS), Undera (GU), McCoy's Bridge (GMc) and at the confluence with the Murray River at Echuca (GEc). Only three tributaries, Pranjip Creek (P), Castle Creek (C) and Seven's Creeks (Se), were suitable for analysis in the lower region. Overall, there are fewer tributaries in the lower Goulburn, compared to the upper (Figure 1). The majority of these sites selected are monitored for flow or water quality and have designated site numbers (Table 1).

A survey of environmental condition under the 'Index for Stream Condition' (http://www.vicwaterdata.net/; accessed January 2004) initiative rated sites in the Goulburn Catchment (Table 1). The survey assessed environmental condition based on changes to hydrology, physical form, streamside zone, water quality and macroinvertebrate indices. Sites along the Goulburn main channel were assessed as between marginal and poor (Table 1). The last survey was conducted in 1999.

Description of Data

Fisheries data were supplied by two agencies: the Department of Sustainability and Environment (DSE) and Department of Primary Industries (DPI). The Lake Nagambie Angling Club supplied additional data for Lake Nagambie. Only data after

1970 were used in analyses. Survey data consisted of site name and location, collection method, and the species and number present.

Fish were collected using a combination of techniques, including electrofishing, fyke nets, piscicide, and fish traps. In some cases, sample methods were not defined. Although the use of multiple sampling techniques can be considered to be poor sampling design, construction of fish assemblages using multiple techniques is widely utilised (eg. Gehrke *et al*. 1999; Brown 2000; Gehrke and Harris 2000; Davies 2001; Gehrke and Harris 2001; Marchetti and Moyle 2001; Meador *et al*. 2003), and can be considered unavoidable when aggregating historical datasets from multiple sources (Fairchild *et al*., 1998; Quinn and Kwak, 2003).

Fish assemblages were constructed using the relative abundance data generated from the monitoring data (Appendix 1). Relative abundance data were used to ensure records was not skewed towards sites sampled more frequently. Stocking data were not used in analyses, as the success of stocking is unknown. All stocked native species are of high value for recreational fishing.

Native fish data were divided into migratory patterns, according to the classifications used in Thorncroft and Harris (2000) (Table 2). Species that undertake only local-scale migrations are designated throughout the paper. The majority of long-scale migratory fish in the Goulburn Catchment are classified as potamodromous (migrating within streams). The short-fin eel is catadromous (migrating from fresh water to the sea to spawn). It is recognised that not all populations of native species follow these patterns in designated areas, but categories are based on current scientific knowledge.

Data interpretation

Species and abundance data were combined according to site location. Diversity at each of the sites was calculated using the Shannon-Weiner Diversity Index (Shannon's H') (Shannon and Weaver 1949). The fish community variables, total fish abundance, number of species, and Shannon's H' at each of the sites were calculated. Analyses were conducted using PRIMER 5.0 (Plymouth Marine Laboratory, UK).. Similarities between sites were calculated using the Bray-Curtis similarity measure (Bray and Curtis 1957). Data were transformed using log (x + 1) to reduce the influence of species with high abundances. Classifications used the group-average linking algorithm. Multi-dimensional scaling (MDS) ordinations were used to view sites in two dimensions. River region and site type (main stem or tributary) were used as factors in the analysis.

Analysis of similarities (ANOSIM) was calculated using the Bray-Curtis similarities (Clarke 1993). This was used to identify the differences between fish communities at each of the site groups. An ANOSIM is a non-parametric permutation procedure applied to the rank similarity matrix generated from the Bray-Curtis similarity measure (Clarke and Warwick 1994) and is analogous to an ANOVA comparing between group and within group variation. Up to 999 random permutations were used to estimate the probability of observed results.

Similarity Percentage (SIMPER) analysis was used to establish which species contributed to observed differences in the data. Species were then ranked by examining the degree to which they contributed to measures of dissimilarity between site groupings (Clarke and Warwick 1994).

Results

Data Quality

The data analyses conducted in this study were based on fisheries survey data from multiple sources. The efficiency of surveying fish at a site is known to vary as a result of many factors, including sampling gear, stream size, stream cover and staff expertise. As with any study analysing fisheries data, caution should be exercised in interpreting data and defining patterns within the data.

To surmount the shortcomings of the dataset used in this study, data were vigorously transformed. Multivariate analyses were conducted using presence/absence data only (results not shown) and results had very similar outputs to the analyses on the abundance dataset. Given that quantitative analyses are far more valuable for gaining an understanding in the relationships between fish communities, results for the abundance dataset are presented.

Fish Fauna

Throughout the Goulburn Catchment, the Department of Primary Industries (DPI) undertakes a fish-stocking program (see Table 1 for locations). In the upper part of the main channel, recorded releases of brown trout and rainbow trout occur each year. As the upper Goulburn Catchment datasets contain Atlantic salmon counts, unrecorded releases must also have occurred, or fish may have escaped from local fish farms. Native fish stocking programs release Macquarie perch, golden perch, Murray cod, and trout cod.

Native to the catchment are barred galaxias, trout cod and Macquarie perch. These species are classified as endangered under the Commonwealth legislation, the *Environmental Protection and Biodiversity Conservation Act* 1999. Silver perch, flat-headed galaxias, mountain galaxias freshwater catfish, Murray cod, river blackfish, and rainbowfish are listed as threatened fauna in the State of Victoria legislation, the *Flora and Fauna Guarantee Act* 1988.0

Community variables

There were 29 fish species in the Goulburn Catchment dataset. Nineteen species are native to the area, 9 of which have long-scale migratory patterns (Table 2). The remainder are alien fish introduced from outside Australia. Native fish made up 47 % of the dataset, with 11 % of these undergoing some migration in their life history. Brown trout, gambusia, and goldfish were clearly the most abundant species in the dataset (Appendix 1). The most abundant native species in the dataset were blackfish, barred galaxias and Australian smelt.

According to the dataset, native fish abundances were particularly low at the Goulburn at Eildon (GEi) and Goulburn at Alexandra (GA) sites (Figure 4A), making up 2 % of fish abundance in the upper main channel dataset, only 0.2 % of these native fish had a long-scale migratory life history pattern. In the lower main channel native fish made up 42 % of fish abundance dataset, 9 % of these native fish having a long-scale migratory life history pattern.

Alien species dominated the Goulburn main channel in both the upper and lower portions of the catchment. In the upper main channel, brown trout and rainbow trout made up 53 and 31 % of abundance data, respectively. In the lower main channel, common carp and goldfish made up 18 and 16 % of abundance data, respectively.

Generally, the number of species and diversity increased with distance from Eildon Dam (Figure 4B & 4C). Despite dams preventing migration, three species of long-scale migratory species were in the upper region dataset. The short-fin eel was found at Eildon. This species can climb dam walls (Gehrke *et al.* 2002), and was possibly attempting to migrate further upstream. Australian smelt was present at both Alexandra and King Parrot Creek. This species is widespread throughout the catchment and can be found in slow and fast flowing waters (Lake 1967). It has a protracted spawning period (Humphries *et al.* 1999) and is not an obligatory migratory species. The Macquarie perch data from King Parrot Creek may represent previous, unrecorded stocking, or represent a remnant local-scale migratory population. The Department of Primary Industries conducts stocking of long-scale migratory species in Hughes Creek and Yea River, and long-scale migratory species data exists for both tributaries.

The abundance of fish and the diversity index at Lake Nagambie was comparable to the lower sites (Figure 4C). Native species were stocked in the lake prior to 1996 (DNRE 2000) but anecdotal evidence suggests the fishery declined in the 1980s. Fisheries data from after 1990 does shows a loss of native obligatory migratory species. Recent data suggests that the most abundant species in the lake are the flat-headed gudgeon and the Australian smelt.

Composition of fish communities

The ordination of sites based on the similarities in species compositions for the entire dataset showed separation between the uppermost and lowermost main channel sites of the catchment (Figure 5a). ANOSIM results were significant for both region and site types (Table 3). Lake Nagambie is placed among sites in the lower group (Figure 5a) but ANOSIM results show the fish community at the site is not significantly different to any other site. The separation of tributaries is not so defined, but they are generally placed on opposing sides of the axis (Figure 5a). When examining regions independently, the lower main channel and tributaries are clearly defined, unlike the upper site types, but ANOSIM results show there were no significant differences within upper and lower regions (Table 3).

Using native fish data only, the MDS ordination site grouping shows separation of site groups based on region and site type (Figure 6a), again the exception is Lake Nagambie site, which is placed with the lower main channel sites. ANOSIM results were again significant for both sites and regions and significant for all upper sites compared to lower sites (Table 3). Unlike the analyses with the complete dataset, the compositions of the native fish communities within the upper main channel were significantly different to those of the upper tributaries. The difference between site communities was also apparent in the lower region (Table 3).

Using SIMPER analysis, the dominance of different species groups at each region and stream type was clear and the dissimilarities between the regions and streams at the main channel sites were predominately due to alien species (Table 4). In the upper main channel reach, introduced salmonids were the most abundant species. In the lower main channel reaches, habitat generalists were the most abundant in the dataset. Dissimilarities between tributaries and the main channel of the upper region were comparatively low (average dissimilarity = 69) compared to comparisons between tributaries and the main channel of the lower reach (average dissimilarity = 82). Dissimilarities between the upper and lower tributaries datasets were due to a mixture of native and alien species (Table 4) The regional fish communities that are comparable were the mid region and the lower main channel (average dissimilarity = 43). The dataset showed high dissimilarities between the fish community in the mid region as compared to those in the upper regions (Table 4).

Discussion

The data analyses conducted in this study were based on fisheries survey data originating from multiple sources, and thus findings are based on data collected using non-standard sampling methodologies. Subsequently, all findings should be treated with caution. Nonetheless, the outcomes of the analyses in this study are clear. The native fish fauna of the Goulburn are clearly under stress due to the altered environmental conditions, with recreational and opportunistic alien species dominating fish abundances. Quinn and Kwak (2003) also combined multiple datasets with non-standard sampling methodologies and concluded that there were dramatic changes in fish communities of the Ozark River that could not be ignored, despite to the shortcomings of the dataset.

To improve the robustness of fisheries datasets for future analyses, monitoring data should incorporate thorough reporting of sampling methodology, the consistent use of sampling and analytical methods, and, if possible, provide length and weight measurements to derive biomass estimates.

Fish communities

Although total fish abundance within each of the regions of the Goulburn catchment was similar, when comparing the abundance of native species and alien species independently, considerable differences were evident. The higher abundance of local-scale migratory fish in the upper tributaries compared to the main channel, and increasing long-scale migratory fish abundance in the lower part of the catchment is clear. Likewise, species diversity in the Goulburn Catchment increased with distance from Eildon Dam, with greater numbers of long-scale migratory species downstream of Goulburn Weir. This indicates that conditions in the upper reaches of the catchment, especially in the main channel, create an unsuitable habitat for native fish, thus forming an artificial barrier to fish habitation and movement.

Unregulated inland rivers of south east Australia traditionally exhibit a downstream reduction in diversity (Gehrke and Harris 2000). After the construction of Tallowa Dam on the Shoalhaven River system (NSW), Gehrke *et al.* (2002) found localised extinctions upstream of the dam had taken place. Fish surveys found long-scale migratory species have mostly disappeared above the dam structure and diversity increased downstream of the dam (Gehrke *et al.* 2002). The construction of Tallowa Dam had caused divergent populations of fish to form upstream and downstream of the structure. Migratory species were observed accumulating at the dam wall and alien species became established (Gehrke *et al.* 2002).

Similar to the Shoalhaven data, there has been a dramatic loss of long-scale migratory species above the barrier Goulburn Weir. Goulburn Weir was constructed in 1889, and as migration in the upper portion of the Goulburn main channel has been prevented over such an extended period, long scale migratory species are mostly absent upstream of the structure.

Eildon Dam has also had a dramatic effect on fish communities upstream of the structure (Cadwallader and Rogan 1977). The lake and feeder streams were once abundant with the obligate long-scale migratory species Macquarie perch, but populations have declined to the point where the species have virtually disappeared and alien species dominate abundance (Cadwallader and Rogan 1977). Despite no evidence of localised extinctions taking place downstream of Eildon dam, it is likely that this has occurred.

In addition to barriers in the lowland Goulburn main channel preventing migration, the thermal regime of the upper main channel has also been altered. As a result of hypolimnetic releases from Eildon Lake, the Goulburn main channel is no longer habitable by native species. However, these altered conditions are highly suitable for the introduced salmonid species which now dominate fish communities, and subsequently the upper main channel is now valued as a recreational trout fishery. The upper tributaries, which are important habitats for native fish communities, are also dominated by introduced recreational species and threaten the survival of many Galaxiid species.

River regulation has also dramatically altered the flow regime in the Goulburn Catchment. Consequently, there are reduced opportunities for recruitment success of native fish species. Wetlands act as important nursery areas and were once filled annually. With the current flow regime, the river floodplain is rarely connected to the river main channel. Moreover, low flows periods during the summer and spring seasons that once occurred as part of the natural flow regime, are now rarely experienced, particularly in the upper main channel. These low flow periods coincided with the reproductive season of native fish. Low flow periods are important determinants in the recruitment success of some native species (Humphries *et al*. 1999; Humphries and Lake 2000).

As there are no pre-regulation fish data for the Goulburn Catchment, the original community composition is unknown; however, the absence of long-scale migratory species above Lake Nagambie, and the paucity of native fish in the upper main channel demonstrate a dramatic change in fish communities as a result of regulation. The pre-regulation conditions in the upper catchment would be suitable for spawning of select native species inhabiting the Goulburn Catchment. Murray cod, Macquarie perch and fish from the Galaxiidae and Gadopsidae families are known to spawn (Koehn and O'Connor 1990) at the pre-regulation water temperatures modelled by Gippel and Finlayson (1993). The presence of Galaxiidae and Gadopsidae families in the upper tributaries demonstrate that where there are no temperature changes and the flow regime is largely intact, native fish communities are viable but currently threatened by stocked recreational salmonids. The absence of native fish in the river main stem suggests that due to thermal changes and changes to the flow regime, they are unable to subsist in this area.

The analyses in this study demonstrate that fish communities in the main channel below Eildon Dam were divergent from those in both the upper tributaries of the catchment, and those downstream of Goulburn Weir, where water temperatures and seasonal flow patterns were unchanged. Only minor hydrological changes occur 200 km downstream of Eildon Dam as a result of flood runoff from tributaries (Erskine 1996), and there are only minor flow changes in tributaries. This finding is comparable to those of previous studies in regulated rivers, which have demonstrated that the effects of flow regulation on stream communities is often most severe below a dam, with effects becoming less severe as tributary inflow and other physical processes mitigate effects (Brown and Ford 2002).

In Lake Nagambie and downstream of Goulburn Weir, although native fish communities are more diverse and abundant than the upper part of the catchment, communities are still threatened. Habitat generalists, such as gambusia, common carp, goldfish and redfin perch have proliferated in the regulated conditions of the mid and lower catchment. Likewise, in the highly regulated lowland Campaspe River also located in northern Victoria, the highly fish fauna is highly degraded, being dominated by common carp and redfin perch (Cadwallader 1978; Humphries and Lake 2000). Although the successful establishment of these alien species is not a direct result of river regulation or continued stocking, the environmental conditions established are often more appropriate for alien species (Ross 1991).

Alien species clearly dominate throughout the Goulburn Catchment, whether the result of stocking or due to fish flourishing in the altered conditions. The requisite conditions for the successful establishment of alien fish varies, but it is generally greater in areas that are altered by humans, or where native fish species are depauperate (Ross 1991). Both conditions exist in the Goulburn Catchment. Therefore, the loss of species diversity upstream of the Goulburn Catchment, but the similar abundances between reaches, suggests that alien species may have replaced the lost native species. The change in flow regime was also an important factor in alien fish becoming established in Putah Creek, California (Marchetti and Moyle 2001).

There is evidence that native species are adversely affected by alien fish species, with some effects being exacerbated by flow regulation (Arthington and McKenzie 1997). Mechanisms that can lead to domination of alien species in regulated rivers include the elimination of suitable spawning habitat and the reduction of habitat for early life stages of native fishes (Cadwallader 1978; Marchetti and Moyle 2000). Populations of alien species can prey directly on native fish, compete with native species for resources such as food and habitat, alter habitat, and introduce foreign pathogens to the native fish population (Ross 1991; Arthington and McKenzie 1997).

As a result of the multiple stressors to native fish in the Goulburn Catchment the basic structures of the fish communities in each portion of the catchment differ from one another. The different stressors in each part of the catchment, and there influence on native fish, show that no one principal cause for the decline in native fish can be identified.

Management recommendations

In the Goulburn Catchment, to assist in the establishment of sustainable native fish communities, where communities of natives are more abundant than alien species, management practices that favour native fish can be introduced. Given that there are multiple threats to native fish in the catchment, the task of rehabilitating fish communities is not simple. Instead management options that include improvements to physical habitat, construction of fishways and introduction of natural elements to flow regimes, should be examined.

Despite the upper main channel of the lowland Goulburn River being largely devoid of native fish, upper tributaries show the capacity to support local-scale migratory native species. The lower main channel and tributaries have the capacity to support both local-scale migratory and long-scale migratory native fish communities. In these areas, maintaining and restoring refugia for native fish should be encouraged. Strategies for improvement can focus largely on removing barriers, and maintaining and restoring physical habitats by replanting native riparian vegetation, barring stock access to streams and re-introducing woody debris. Natural flow regimes in these streams should also be restored or maintained and the stocking of introduced salmonids in these areas be re-evaluated.

Lake Nagambie supports select native species in its current state, and the management of the lake should be examined to determine if it is possible to facilitate the establishment of a more diverse native fish population. The construction of a fishway at Goulburn Weir is feasible and would increase the diversity and abundance of fish in Lake Nagambie. Maintaining and improving the diversities of physical habitats, the water quality and rehabilitating stream flow in Lake Nagambie and the lower Goulburn would also be beneficial. Cold-water pollution from Eildon Dam rarely extends beyond Seymour (Gippel *et al.* 1993), and would not be detrimental to native fish in this area. As concluded by Gehrke *et al.* (2002), by restoring fish passage and reducing the discontinuity of dams, fishways constitute a key component of rebuilding riverine ecosystems, and restoring degraded fish communities. Migration is an essential part of the life cycle for the threatened species golden perch and silver perch, and to a lesser extent Murray cod (Reynolds 1983).

Much evidence exists that restoration or preservation of aquatic biota requires the restoration of natural flow regimes, in addition to habitat and water quality (Poff *et al.* 1997; Brown and Ford 2002). By increasing the stability of flows and reducing the frequency of disturbance, river regulation has disadvantaged specialist fish species while favouring generalist species (Cadwallader 1978; Humphries and Lake 2000; Gehrke and Harris 2001). In the Murray Darling Basin, Humphries *et al*. (1999) and Humphries and Lake (2000) have examined the elements of flow and water quality that are important for successful recruitment of native fish species. Although a number of fish species in the regulated rivers can spawn each year despite the variations in patterns of flow and temperature, there is mounting evidence supporting the hypothesis that the majority of native species in the Basin successfully recruit during spring and summer low flow periods.

Clearly the introduction of a near natural flow regime below Eildon Dam is complicated by the thermal changes and the importance of irrigation activities in the catchment. However, the present flow regime in the Goulburn River could be improved by adopting some recommendations of Cottingham *et al.* (2003). These include: (a) provision of an annual floodplain and wetland inundation event of varying magnitude at all reaches, (b) applying upper limits to summer-autumn flows between Eildon and Lake Nagambie, and (c) ensuring that rates of rise and fall in river levels are within the natural range between Eildon and at Loch Garry, which is downstream of Shepparton.

Given the poor state of the native fishery, Gippel and Finlayson (1993) proposed managing the Goulburn fishery for two purposes: in the upper Goulburn River maintain current practices and manage the fishery for recreational purposes by continuing to stock with introduced salmonids; and in the lower Goulburn River manage the region as a native fishery. In the short term this approach may be possible but improved management in the lower portion of catchment alone cannot restore all communities of native fish. What is not considered in this scenario is the importance of the upper tributaries, which are valuable habitats for many native local-scale migratory fish species, and Lake Nagambie, which has the potential to be rehabilitated and act as an important habitat for both long-scale migratory and local-scale migratory fish species.

The conditions for maintaining a trout fishery in the upper portion of the catchment conflict with the conditions required for restoration of a number of fish species once native to this area. The loss of suitable habitat and increased competition in the upper reaches of the catchment has lead to a decline in threatened Galaxiid species, the river blackfish, Murray cod, and Macquarie perch, where pre-regulation conditions would have been suitable for spawning. The feasibility of mitigating temperature changes via a multi-level offtake from Eildon Dam requires investigation in order to rehabilitate native fish communities throughout the entire lowland Goulburn Catchment.

Conclusion

The majority of fish species native to the Goulburn Catchment are listed as being either endangered or threatened, and without management interventions the future of many of Australian native fish species is bleak. The current status of native fish in the Goulburn Catchment is a direct result of historic management, which was based primarily on meeting anthropogenic needs. Recently, a greater awareness of the importance of protecting and restoring the health of catchments for the purposes of achieving ecological sustainability has been achieved.

This study confirms that native fish communities in the Goulburn Catchment are fragmented, and lends support to the approach that future management options in the catchment should focus on fish communities and manage environmental stressors in their entirety. An essential component of such a management approach is routine monitoring of fish populations in the Goulburn Catchment. Routine monitoring is a vital component to strategies utilising an adaptive management approach. Monitoring will facilitate both the assessment of outcomes of management actions and improved understanding of factors influencing fish populations.

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Table 1: Site information and location of lowland river sites in the Goulburn Catchment ('a' denotes stocking of alien salmonids, and 'n' denotes stocking of natives).

Region	Type	Stream	Nearest town, landmark, roadway	Site no.	Site code	Latitude	Longitude	Stocking	ISC score
Upper	Main	Goulburn River	Eildon	405203	GEi	-37.250	145.870	a	Poor
		Goulburn River	Alexandra	-	GA	-37.170	145.510	a	Poor
		Goulburn River	Yea	-	GY	-37.184	145.369	-	Very Poor
		Goulburn River	Trawool	405201	GT	-37.090	145.200	-	Very Poor
Upper	Tributary	Rubicon River	Rubicon	405241	R	-37.290	145.820	a	-
		Taggerty River	Lady Talbot Dve	-	T	-37.290	145.510	a	Excellent
		Acheron River	Taggerty	405209	A	-37.320	145.710	a	Excellent
		Murrindindi River	Above Colwells	405209	M	-37.410	145.560	a	Marginal
		Yea River	Devlins Bridge	405217	Y	-37.380	145.470	an	Marginal
		King Parrot Creek	Flowerdale	405231	K	-37.350	145.290	a	Marginal
		Sunday Creek	Tallarook	405212	Su	-37.380	145.050	a	Marginal
		Hughes Creek	Tarcombe Rd	405228	H	-36.950	145.280	an	Marginal
Mid	Main	Lake Nagambie	Nagambie	-	GN	-36.470	145.800	an	-
Lower	Main	Goulburn River	Murchison	405200	GMu	-36.620	145.220	n	Poor
		Goulburn River	Shepparton	405200	GS	-36.380	145.390	n	Poor
		Goulburn River	McCoys Bridge	405232	GMc	-36.180	145.120	-	Poor
		Goulburn River	Undera	-	GU	-36.277	145.342	-	Poor
		Goulburn River	Echuca	-	GEc	-36.135	145.002	-	Poor
Lower	Tributary	Pranjip Creek	Moorilim	405226	P	-36.620	145.310	-	Marginal
		Castle Creek	Arcadia	405246	C	-36.590	145.350	-	Marginal
		Seven's Creek	Polly McQuinn Weir	405234	Se	-36.890	145.680	n	Marginal

Table 2: Native fish species (n) and alien species (a) found in the Goulburn Catchment. Allocation of migratory pattern were made using Thorncroft and Harris (2000) ('a' indicates stocking of alien salmonids, and 'n' indicates stocking of natives).

Common Name	**Scientific Name**	*Migratory Pattern* *	*n/a*
Atlantic salmon	*Salmo salar*	Local-scale	a
Australian smelt	*Retrospinna semoni*	Potamodromous	n
Barred galaxia	*Galaxias fuscus*	Local-scale (?)	n
Bony bream	*Nematalosa erebi*	Potamodromous	n
Blackfish	*Gadopsis marmoratus*	Local-scale	n
2-Spined blackfish	*Gadopsis bispinosus*	Local-scale	n
Brown trout	*Salmo trutta*	Local-scale	a
Carp	*Cyprinus carpio*	Local-scale /Potamodromous	a
Catfish	*Tandanus tandanus*	Local-scale	n
Goldfish	*Carassius auratus*	Local-scale /Potamodromous	a
Golden pPerch	*Macquaria ambigua*	Potamodromous	n
Flat-headed Galaxias	*Galaxias rostratus*	Local-scale	n
Flat-headed Gudgeons	*Philyphodon grandiceps*	Local-scale (?)	n
Hybrid carp	*Cyprinus carpio x Carassius auratus*	Local-scale /Potamodromous	a
Macquarie perch	*Macquaria australasica*	Potamodromous	n
Mirror carp	*Cyprinus carpio*	Local-scale /Potamodromous	a
Mosquitofish	*Gambusia affinis / Gambusia holbrooki*	Local-scale (?)	a
Mountain galaxia	*Galaxias olidus*	Local-scale	n
Murray cod	*Maccullochella peeli*	Potamodromous	n
Pygmy perch	*Nannoperca australis*	Potamodromous (?)	n
Rainbowfish	*Melanotaenia fluviatilis*	Local-scale	n
Rainbow trout	*Oncorhychus mykiss*	Local-scale	a
Redfin	*Perca fluviatilis*	Potamodromous	a
Short-finned eel	*Anguilla australis*	Catadromous	n
Silver perch	*Bidyanus bidyanus*	Potamodromous	n
Tench	*Tinca tinca*	Local-scale (?)	a
Trout cod	*Maccullochella macquariensis*	Potamodromous (?)	n
Western carp gudgeon	*Hyperseleotris klunzingeri*	Local	n

Table 3: Summary of ANOSIM results using waterway region and site type as factors.

Data	Source	R-value	Probability
All	Differences between regions	0.778	0.001
	Differences between site type	0.248	0.015
	Pairwise tests:		
	Upper Main vs. Upper Trib	0.088	0.240
	Upper Main vs. Mid Main	1.000	0.200
	Upper Main vs. Lower Main	1.000	0.008
	Upper Main vs. Lower Trib	0.963	0.029
	Upper Trib vs. Mid Main	0.839	0.111
	Upper Trib vs. Lower Main	0.912	0.001
	Upper Trib vs. Lower Trib	0.608	0.006
	Mid Main vs. Lower Main	0.200	0.333
	Mid Main vs. Lower Trib	0.333	0.750
	Lower Main vs. Lower Trib	0.569	0.054
Natives	Differences between regions	0.477	0.001
	Differences between site type	0.510	0.001
	Pairwise tests:		
	Upper Main vs. Upper Trib	0.424	0.018
	Upper Main vs. Mid Main	0.833	0.200
	Upper Main vs. Lower Main	0.800	0.008
	Upper Main vs. Lower Trib	1.000	0.067
	Upper Trib vs. Mid Main	0.848	0.111
	Upper Trib vs. Lower Main	0.907	0.002
	Upper Trib vs. Lower Trib	0.355	0.048
	Mid Main vs. Lower Main	0.200	0.333
	Mid Main vs. Lower Trib	0.778	0.250
	Lower Main vs. Lower Trib	0.733	0.018

Table 4: SIMPER analysis showing species contributing to the greatest differences between fish communities in select parts of the Goulburn Catchment.

Species	**Mean Abundance**		**Ratio**	**%**	**Cumulative %**
Upper Main & Lower Main: mean dissimilarity = 95.47					
Salmo trutta	31.3	0.07	6.92	40.0	39.95
Oncorhynchus mykiss	5.74	0.07	2.30	8.15	48.10
Gambusia holbrooki	0.08	12.5	1.14	7.86	55.97
Cyprinus auratus	0.08	3.99	1.69	6.60	62.57
Cyprinus carpio	0.08	11.3	2.61	6.43	68.99
Upper Main & Lower Tributaries: mean dissimilarity = 86.89					
Salmo trutta	31.3	0.03	7.30	17.2	17.22
Hyperseleotris klunzingeri	0.01	6.67	1.75	10.0	27.25
Nannoperca australis	0.08	9.84	2.32	10.0	37.28
Oncorhynchus mykiss	5.74	0.84	2.31	8.95	46.23
Gadopsis mamoratus	0.00	9.47	1.15	7.07	53.29
Upper Trib & Lower Tributaries: mean dissimilarity = 78.56					
Salmo trutta	5.26	0.03	2.51	11.3	11.33
Hyperseleotris klunzingeri	0.00	6.77	1.83	10.5	21.80
Nannoperca australis	0.32	9.84	2.17	10.2	31.97
Gadopsis mamoratus	4.99	9.47	1.30	7.71	36.69
Gadopsis bispinopsis	2.81	0.01	0.99	7.14	46.83
Upper Tributaries & Lower Main: mean dissimilarity = 95.47					
Salmo trutta	5.26	0.07	1.44	12.0	11.97
Gadopsis mamoratus	4.99	0.08	0.78	11.2	23.14
Gadopsis bispinopsis	2.81	0.00	0.66	9.41	32.56
Gambusia holbrooki	0.01	12.5	1.16	7.99	40.55
Galaxias fuscus	5.25	0.00	0.57	6.74	47.29
Upper Main & Mid Main: mean dissimilarity = 95.90					
Salmo trutta	31.3	0.20	6.25	40.1	40.08
Philypnodon grandiceps	0.31	36.2	50.0	17.5	57.56
Retrospinna semoni	0.04	19.8	88.4	9.78	67.34
Cyprinus carpio	0.08	17.3	39.0	8.48	75.82
Oncorhynchus mykiss	5.74	0.01	2.18	8.45	84.27
Upper Tributaries & Mid Main: mean dissimilarity = 94.18					
Philypnodon grandiceps	0.31	36.2	43.8	18.1	18.14
Salmo trutta	5.26	0.20	1.38	12.3	30.49
Gadopsis mamoratus	4.99	0.80	0.73	11.3	41.76
Retropinna semoni	0.01	19.8	149	9.99	51.75
Gadopsis bispinopsis	2.81	0.00	0.62	9.54	61.29
Mid Main & Lower Tributaries: mean dissimilarity = 82.51					
Philypnodon grandiceps	36.2	0.00	14.9	14.3	14.34
Nannoperca australis	0.00	9.84	2.57	11.1	25.43
Hyperseleotris klunzingeri	0.00	6.77	1.56	10.6	35.59
Retrospinna semoni	19.8	0.87	2.47	7.44	43.03
Perca fluviatilis	16.6	2.04	1.39	6.89	49.92
Lower Main & Lower Tributaries: mean dissimilarity = 81.95					
Nannoperca australis	0.00	9.84	3.03	10.1	10.12
Cyprinus auratus	11.3	0.37	2.53	7.58	17.70
Hyperseleotris klunzingeri	0.32	677	1.53	7.05	24.75
Melanotaenia fluviatilis	5.13	0.00	4.22	6.98	31.72
Gambusia holbrooki	12.5	2.92	1.46	6.70	38.42

Figure Captions

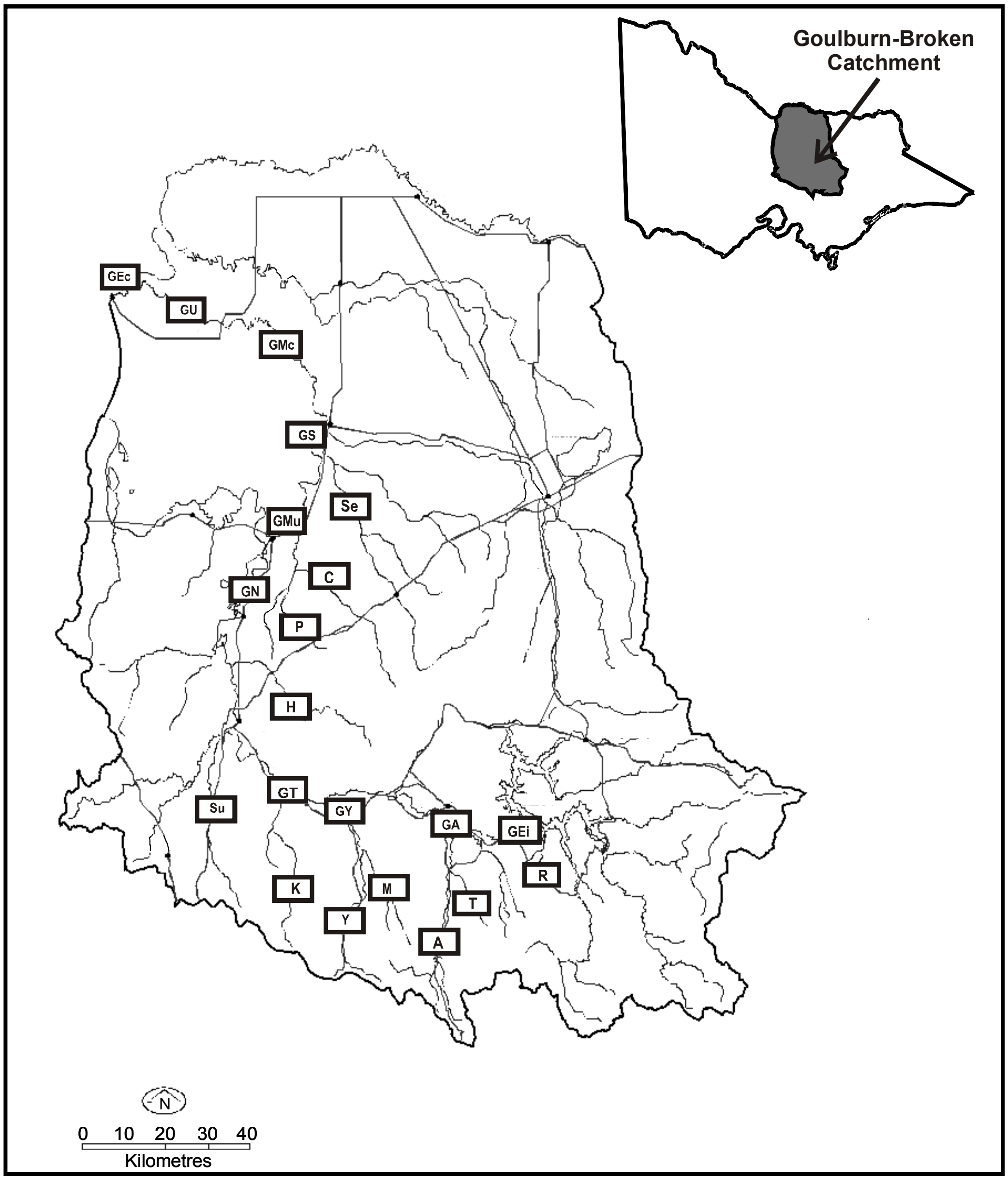
Figure 1: Map of the Goulburn Catchment, south-east Australia (see table 1 for definition of site symbols).

Figure 2: Mean (SD) monthly pre-regulation and post regulation flows for Sugarloaf Dam (1921 - 1954) and Eildon Dam (1954 - 2002). Figures above bars represent the percentage change of means between pre-regulation and post-regulation flows.

Figure 3: Modelled (assuming no dam at Eildon) and observed temperature at Eildon. Model was recreated and updated using updated temperature records according to the methods of (Gippel *et al.* 1993).

Figure 4: Fish community variables at each site of interest in the Goulburn Catchment: (a) Relative abundance of fish species, (b) Number of fish species, and (c) Shannon Diversity (H').

Figure 5: (a) MDS ordination of species from sites showing relationships between the abundances of all fish in the Goulburn Catchment; (b) MDS ordination of species from sites showing relationships between the abundances of native fish in the Goulburn Catchment.


Goulburn-Broken Catchment
GEc
GU
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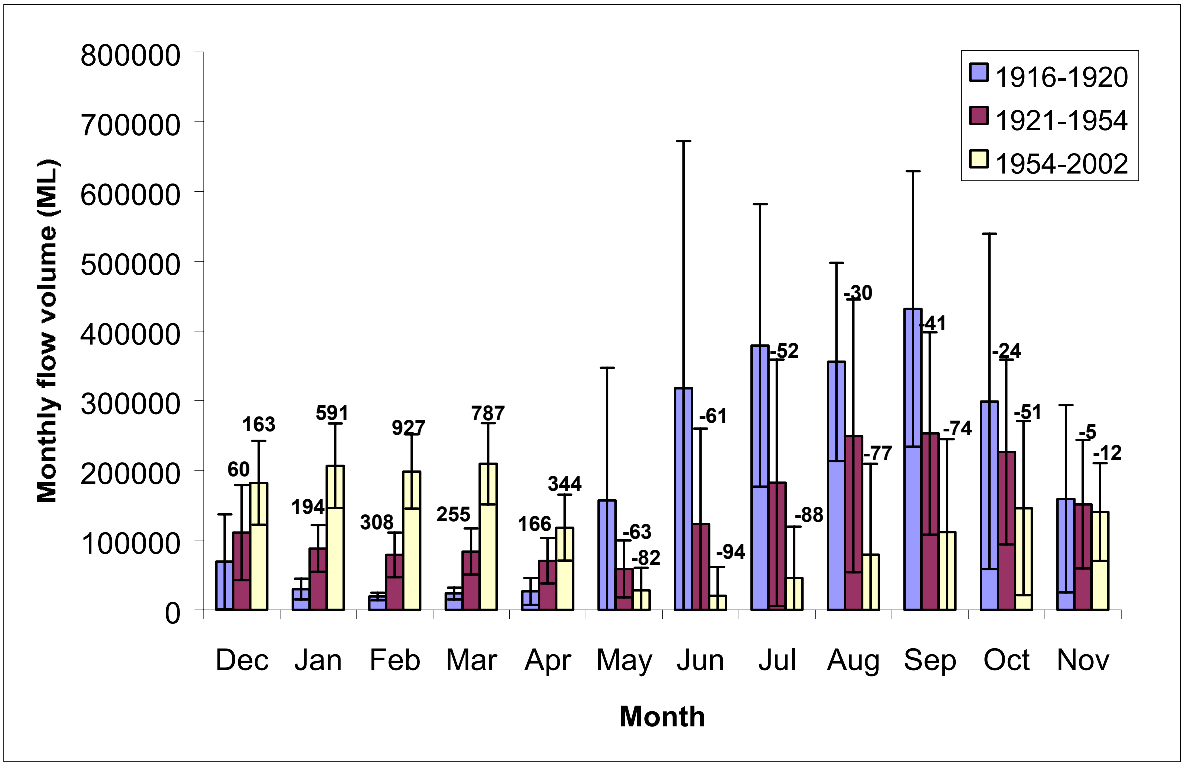
Kilometres


800000
700000
600000
500000
400000
300000
200000
100000
0
Monthly flow volume (ML)
1916-1920
1921-1954
1954-2002
60
163
194
591
308
927
255
787
166
344
-63
-82
-61
-94
-52
-88
-30
-77
-41
-74
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-51
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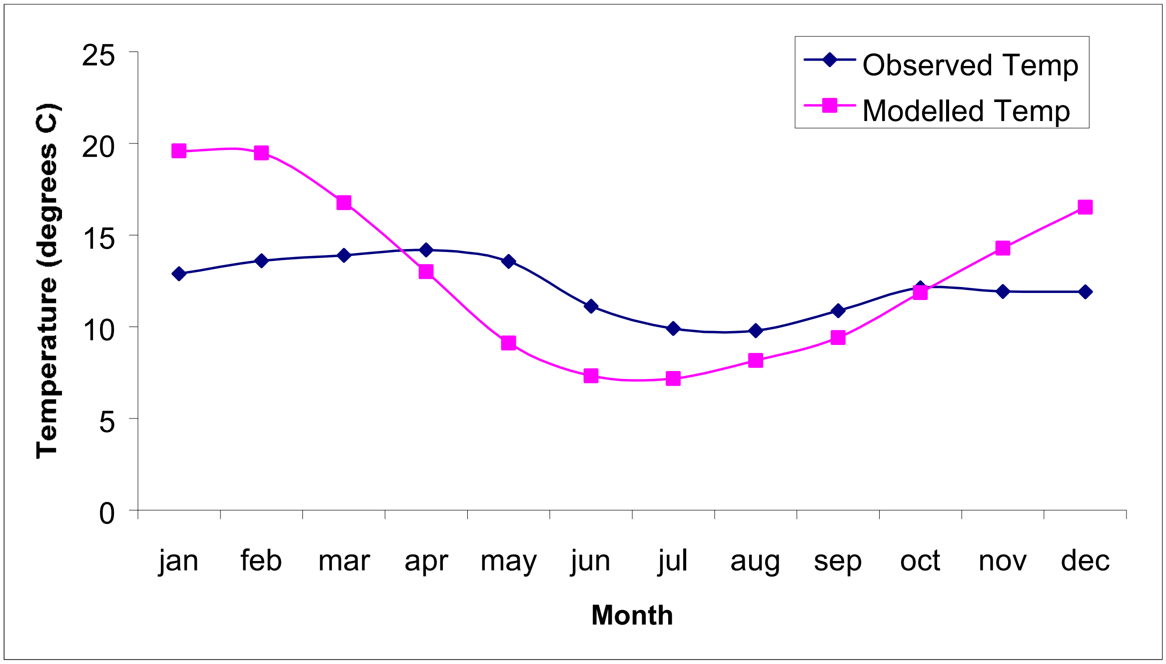
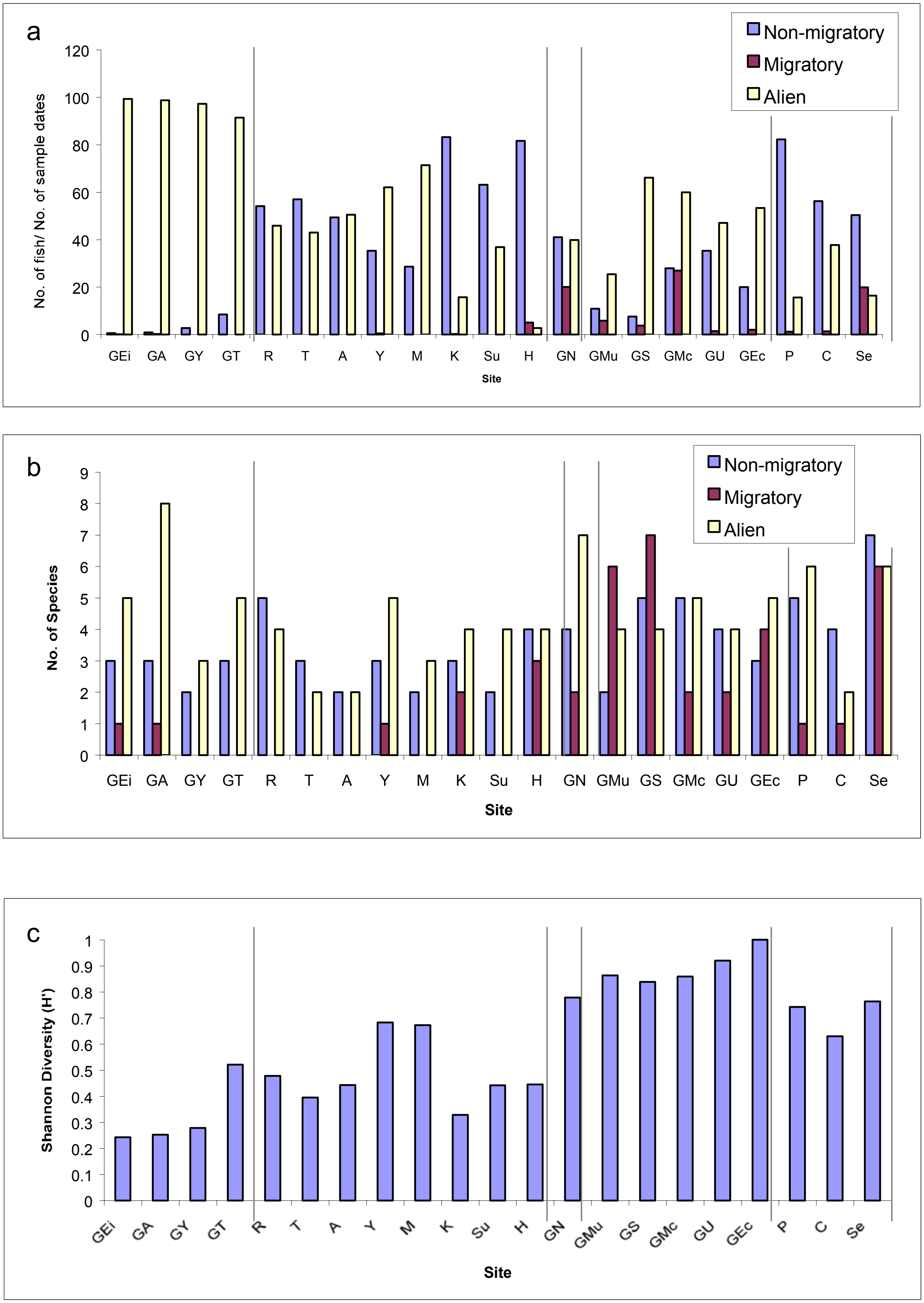


Observed Temp
Modelled Temp
Temperature (degrees C)
25
20
15
10
5
0
jan
feb
mar
apr
may
jun
jul
aug
sep
oct
nov
dec
Month


a
Non-migratory
Migratory
Alien
No. of fish/ No. of sample dates
120
100
80
60
40
20
0
GEi GA GY GT R T A Y M K Su H GN GMu GS GMc GU GEc P C Se
Site
b
Non-migratory
Migratory
Alien
No. of Species
9
8
7
6
5
4
3
2
1
0
GEi GA GY GT R T A Y M K Su H GN GMu GS GMc GU GEc P C Se
Site
c
Shannon Diversity (H')
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
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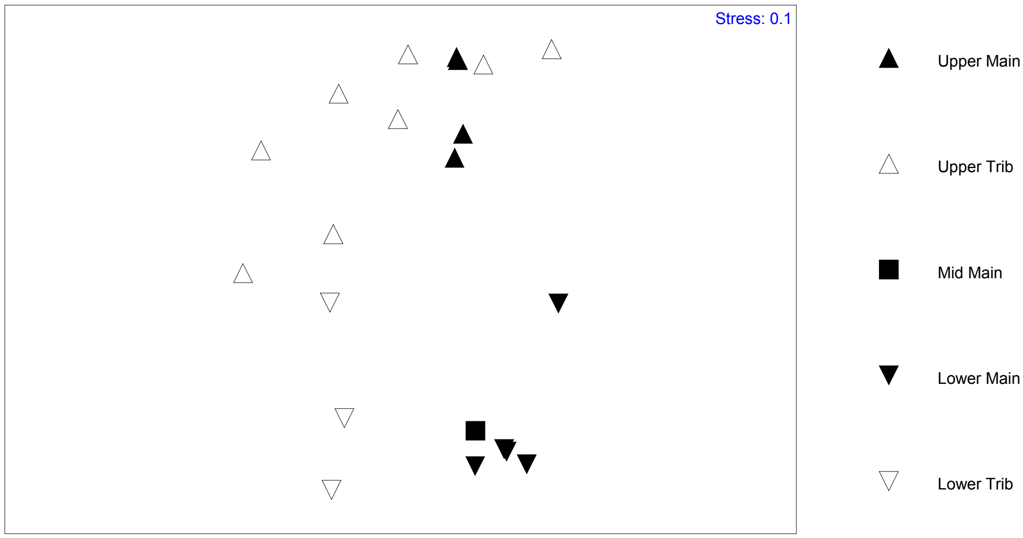
Site

a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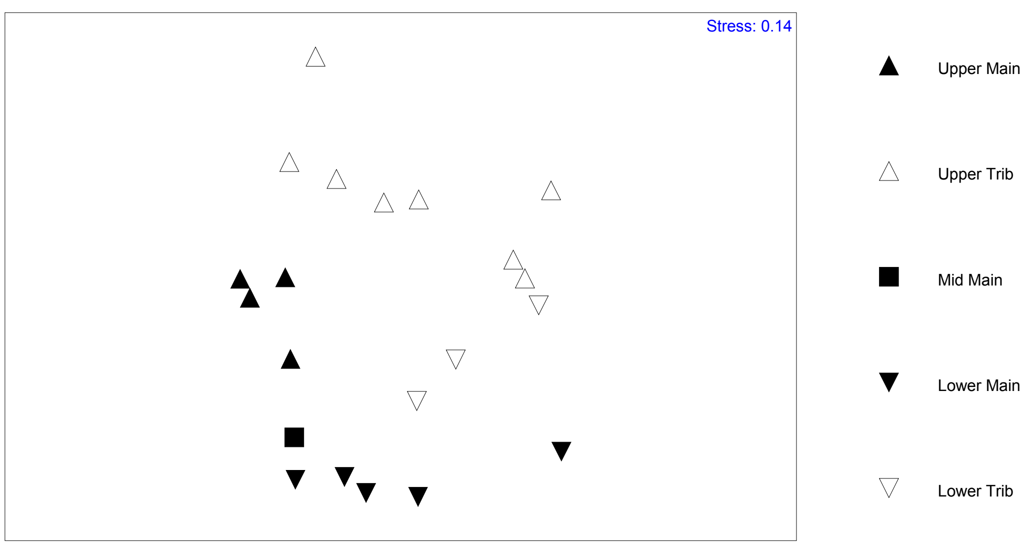
Upper Main
Upper Trib
Mid Main
Lower Main
Lower Trib

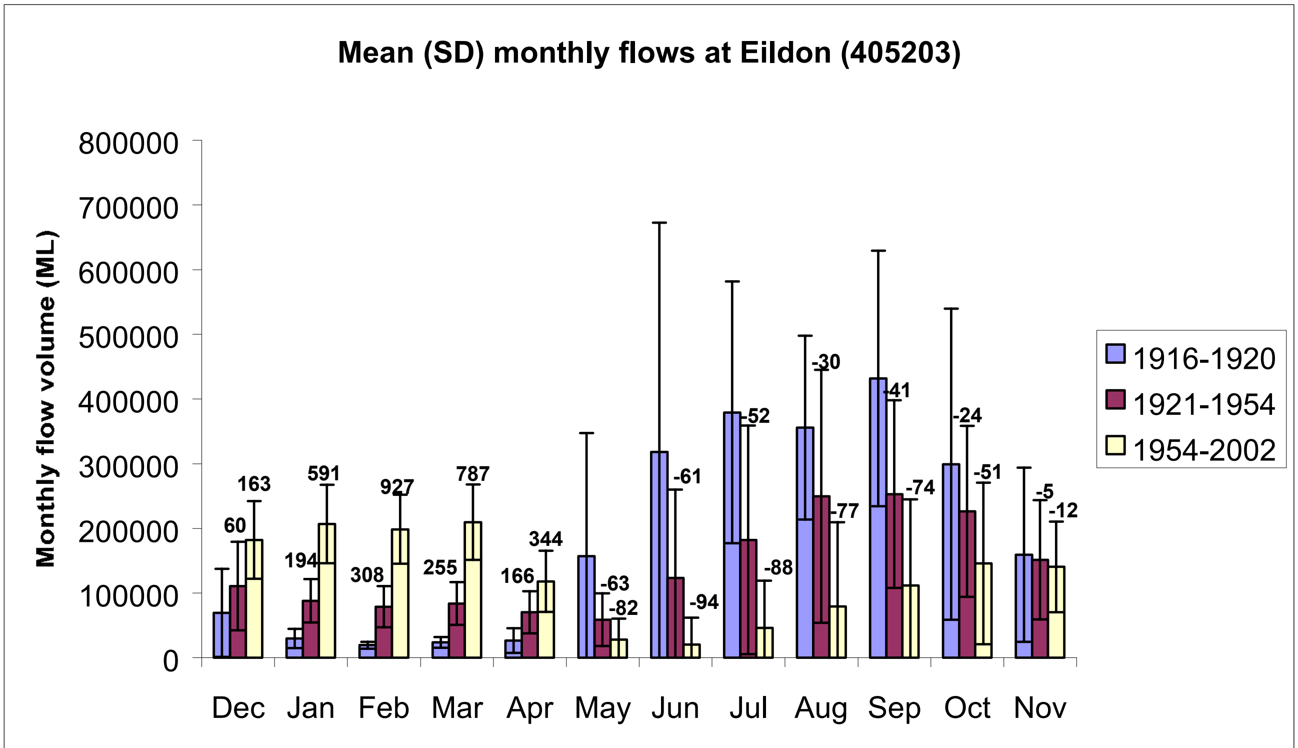
b

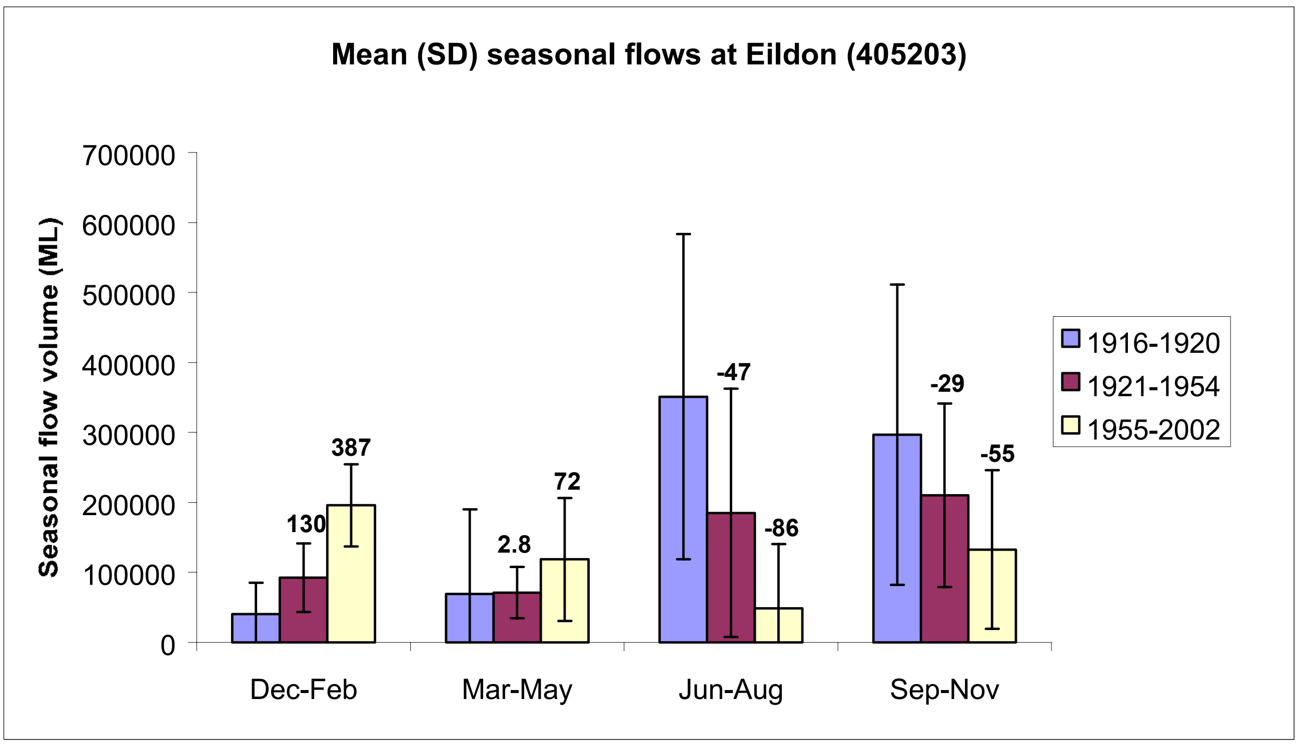

Stress: 0.14
Upper Main
Upper Trib
Mid Main
Lower Main
Lower Trib

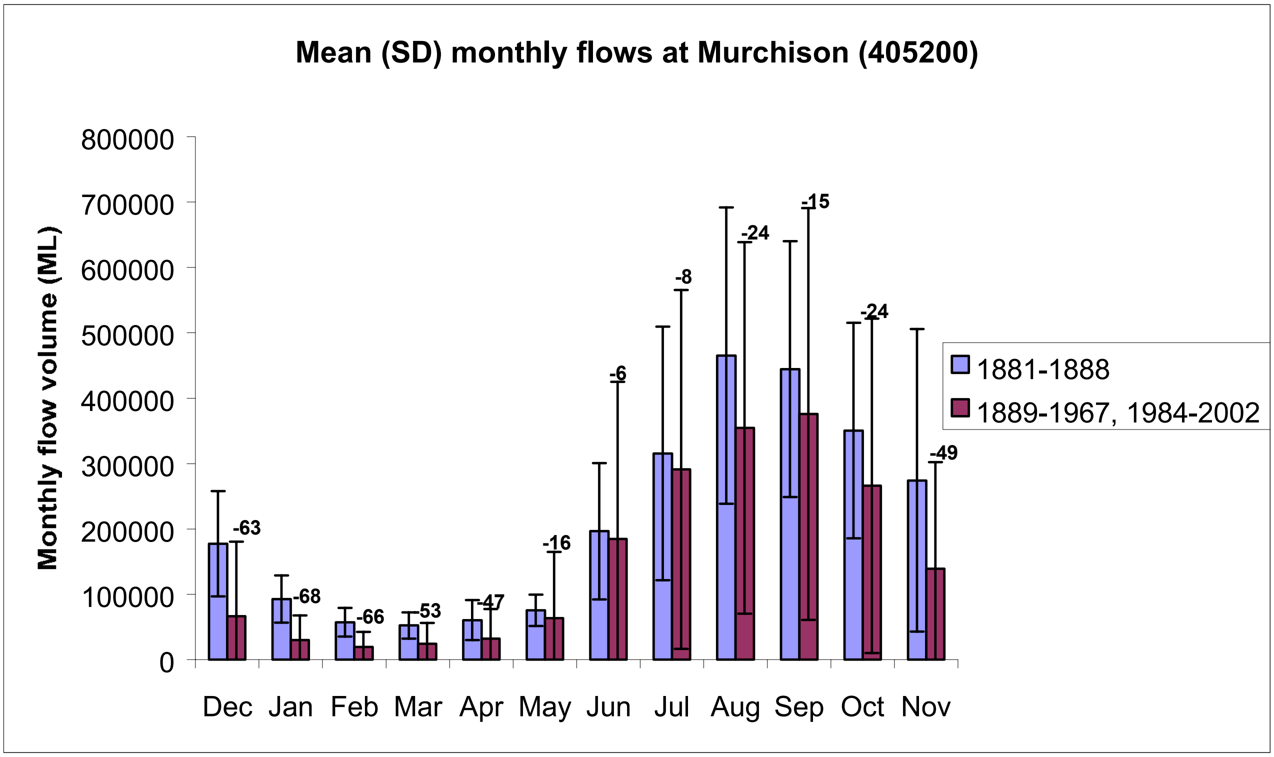
Appendix 1: Summary of fish assemblages, using transformed abundances (see table 1 for definition of site symbols).

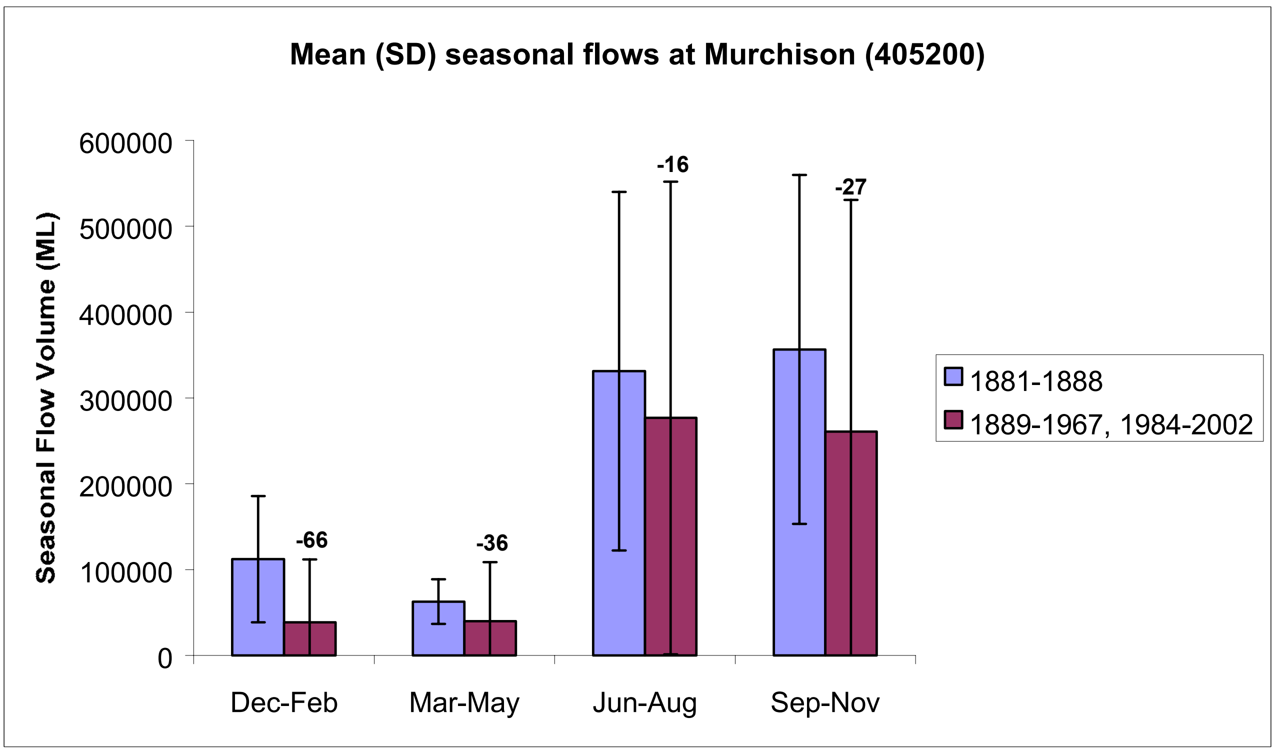
	Upper Main				Upper Tributary								Mid	Lower Main					Lower Tributary		
	GEi	**GA**	**GY**	**GT**	**R**	**T**	**A**	**Y**	**M**	**K**	**Su**	**H**	**GN**	**GMu**	**GS**	**GMc**	**GU**	**GEc**	**P**	**C**	**Se**
Hypseleotris klunzingeri	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.3	0.5	0.8	12	7.7	0.7
Hypseleotris sp.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.5	0.0	0.4	20	0.5	0.0	1.9	0.5	0.0
Philypnodon grandiceps	0.2	0.2	0.6	0.3	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.7	36	0.0	0.0	17	1.5	0.5	0.0	0.0	0.0
Galaxias rostratus	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.5	0.0	0.0	0.0	0.0	0.0
Galaxias fuscus	0.0	0.0	0.0	0.0	27	15	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Galaxias olidus	0.0	0.0	0.0	0.0	0.2	0.2	0.6	0.6	0.0	0.3	0.1	1.9	0.0	0.0	0.0	0.0	0.0	0.0	3.9	1.0	1.1
Gadopsis bispinosus	0.1	0.1	0.6	0.8	3.1	0.3	4.1	0.0	0.2	15	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Gadopsis mamoratus	0.0	0.0	0.0	0.0	0.2	0.0	0.0	3.8	0.2	0.4	12	24	0.8	0.3	0.0	0.0	0.0	0.0	2.8	0.0	26
Anguilla (short fin eel)	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Nannoperca australis	0.1	0.0	0.0	0.3	0.0	0.0	0.0	2.3	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	23	3.5	2.5
Macquaria australasica	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.0	0.1	0.0	4.2	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	12
Macquaria ambigua	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	2.0	0.6	0.3	0.5	0.3	0.0	0.0	0.2
Maccullochella macquariensis	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7	0.0	3.0	0.0	0.0	0.0	0.0	0.0	0.0	7.6
Maccullochella peeli	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.2	0.6	0.0	0.0	0.3	0.0	0.0	0.1
Melanotaenia fluviatilis	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7	0.5	23	0.5	0.3	0.0	0.0	0.0
Retropinna semoni	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	20	0.0	2.4	26	1.0	1.3	1.1	1.3	0.2
Nematalosa erebi	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0
Bidyanus bidyanus	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.0	0.0	0.0	0.3	0.0	0.0	0.1
Tandanus tandanus	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Mordacia mordax	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Gambusia holbrooki	0.0	0.1	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	2.7	0.0	5.1	56	0.5	0.8	0.4	8.3	0.0
Cyprinus carpio	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	17	1.3	2.9	14	1.0	0.8	5.3	0.2	2.2
Cyprinus auratus	0.0	0.1	0.0	0.3	0.2	0.0	0.0	0.4	0.0	0.0	0.1	0.2	4.6	0.3	1.0	52	1.5	1.0	0.9	0.0	0.2
Carassius x Cyprinus hybrid	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.0	0.0	0.3	0.4	0.0	0.0
Tinca tinca	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.4	0.1	0.2	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0
Perca fluviatilis	0.4	0.6	0.2	0.5	0.3	0.0	0.0	4.3	0.2	0.1	0.1	0.3	16	0.0	0.5	5.5	1.0	1.3	1.4	0.0	4.7
Oncorhynchus mykiss	8.5	2.8	8.0	3.8	2.3	10.6	0.6	0.0	0.3	0.2	0.0	0.0	0.1	0.3	0.0	0.0	0.0	0.0	0.0	0.0	2.5
Salmo trutta	51	31	35	8.8	23	1.1	4.2	7.0	0.3	2.6	3.3	0.3	0.2	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.1
Salmo salar	0.8	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Local-scale migratory	0.4	0.3	1.2	1.3	31	16	4.7	6.6	0.3	16	12	26	43	1.0	1.1	62	3.0	1.5	44	13	30
Long-scale migratory	0.1	0.2	0.0	0.0	0.0	0.0	0.0	0.5	0.0	0.2	0.0	5.1	20	5.8	3.8	27	1.5	2.0	1.1	1.3	20
Alien	61	35	43	14	26.0	12	4.8	12	0.8	2.9	7.0	0.9	42	2.3	9.5	133	4.0	4.0	8.4	8.5	9.8
Total	61	35	44	15	57	27	9.4	19	1.2	19	19	32	105	9.2	14	222	8.5	7.5	54	23	60

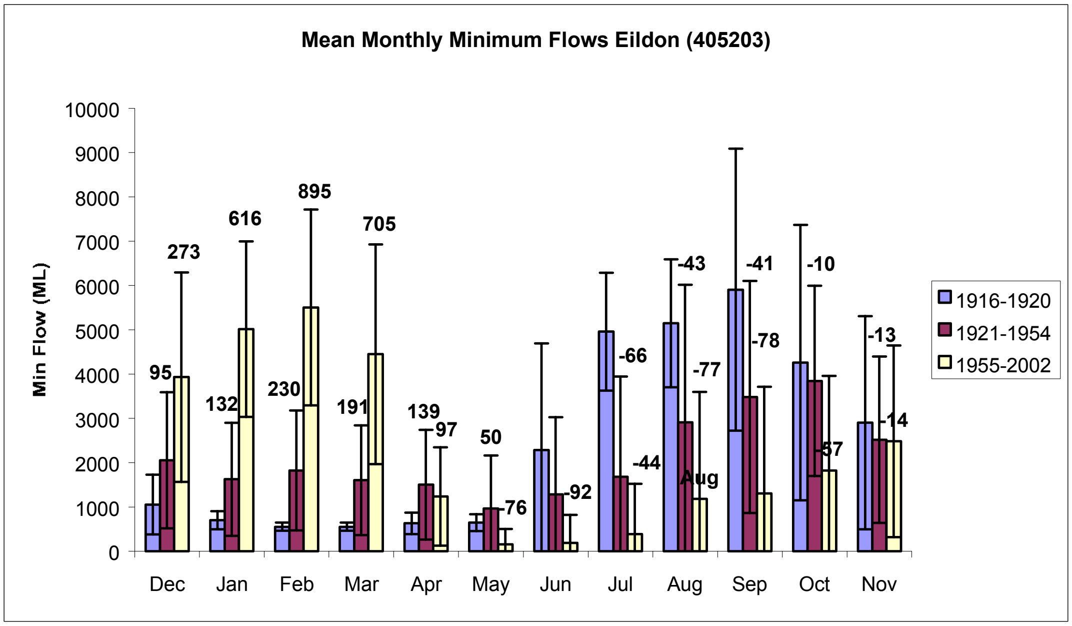
APPENDIX 2

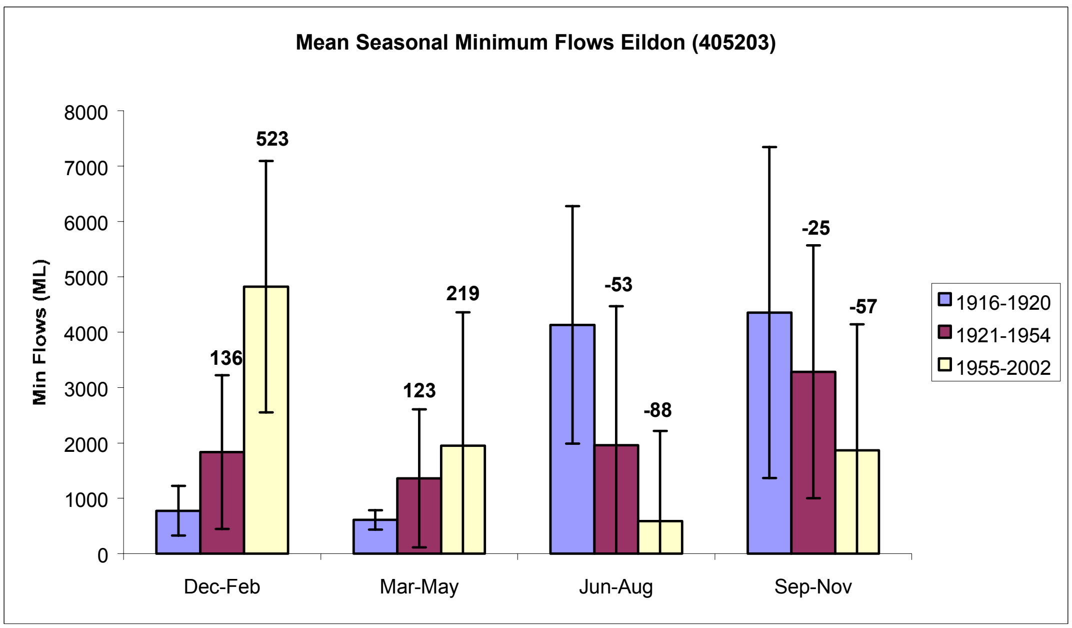

Mean (SD) monthly flows at Eildon (405203)
Monthly flow volume (ML)
800000
700000
600000
500000
400000
300000
200000
100000
0
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
60
163
194
591
308
927
255
787
166
344
-63
-82
-61
-94
-52
-88
-30
-77
-41
-74
-24
-51
-5
-12
1916-1920
1921-1954
1954-2002

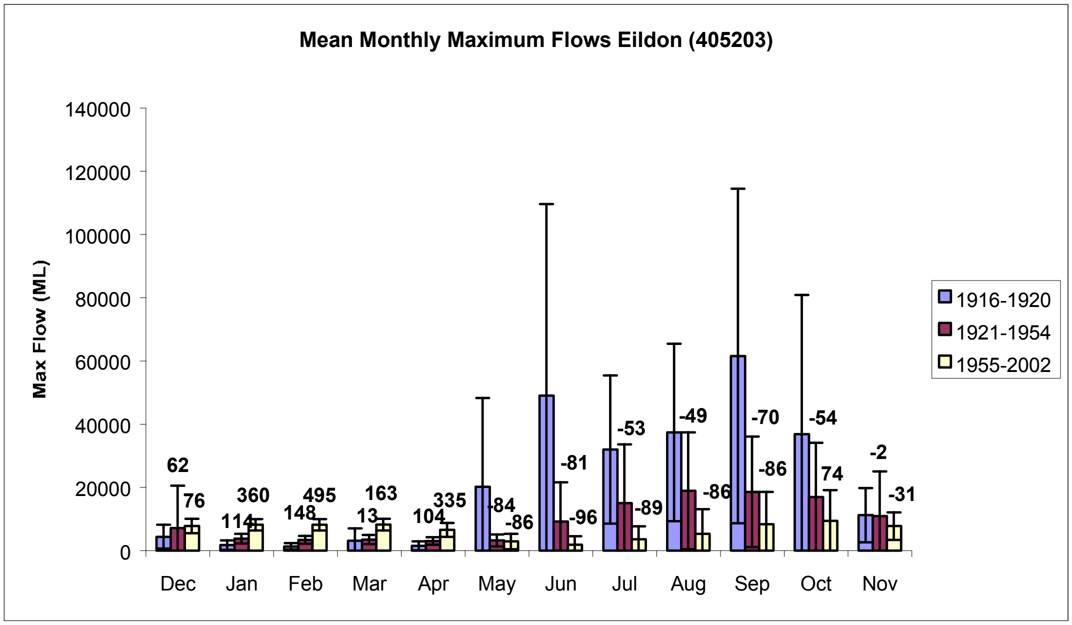

Mean (SD) seasonal flows at Eildon (405203)
Seasonal flow volume (ML)
700000
600000
500000
400000
300000
200000
100000
0
Dec-Feb
Mar-May
Jun-Aug
Sep-Nov
130
387
2.8
72
-47
-86
-29
-55
1916-1920
1921-1954
1955-2002

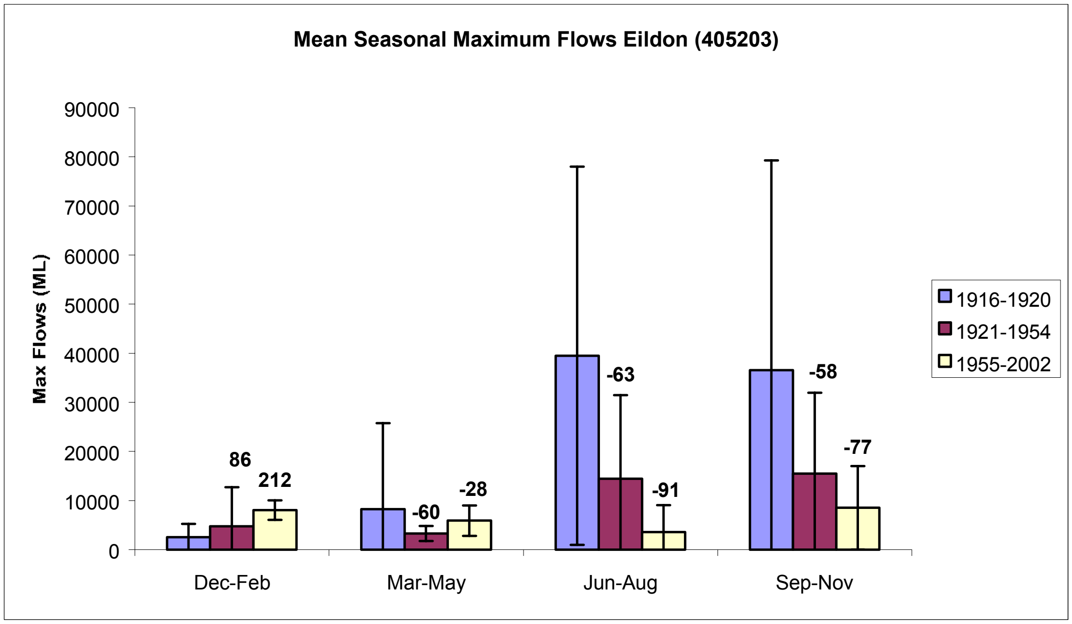

Mean (SD) monthly flows at Murchison (405200)
Monthly flow volume (ML)
800000
700000
600000
500000
400000
300000
200000
100000
0
-63
-68
-66
-53
-47
-16
-6
-8
-24
-15
-24
-49
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
1881-1888
1889-1967, 1984-2002


Mean (SD) seasonal flows at Murchison (405200)
Seasonal Flow Volume (ML)
600000
500000
400000
300000
200000
100000
0
-66
-36
-16
-27
Dec-Feb
Mar-May
Jun-Aug
Sep-Nov
1881-1888
1889-1967, 1984-2002


Mean Monthly Minimum Flows Eildon (405203)
Min Flow (ML)
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
95
273
132
616
230
895
191
705
139
97
50
-76
-92
-66
-44
-43
-77
-41
-78
-10
-57
-13
-14
1916-1920
1921-1954
1955-2002


Mean Seasonal Minimum Flows Eildon (405203)
Min Flows (ML)
8000
7000
6000
5000
4000
3000
2000
1000
0
Dec-Feb
Mar-May
Jun-Aug
Sep-Nov
136
523
123
219
-53
-88
-25
-57
1916-1920
1921-1954
1955-2002


Mean Monthly Maximum Flows Eildon (405203)
Max Flow (ML)
140000
120000
100000
80000
60000
40000
20000
0
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
62
76
114
360
148
495
13
163
104
335
-84
-86
-81
-96
-53
-89
-49
-86
-70
-86
-54
74
-2
-31
1916-1920
1921-1954
1955-2002


Mean Seasonal Maximum Flows Eildon (405203)
Max Flows (ML)
90000
80000
70000
60000
50000
40000
30000
20000
10000
0
Dec-Feb
Mar-May
Jun-Aug
Sep-Nov
86
212
-60
-28
-63
-91
-58
-77
1916-1920
1921-1954
1955-2002

APPENDIX 3

Future Abundance

Findings set: Site = G_Eildon

Entropy of Future Abundance:	0.386506
Future Diversity:	0.046391
Water Quality Habitat Descriptor:	0.01806
Hydraulic Habitat Descriptor:	0.00818
Natives Biological Potential Descriptor:	0.00073
Temperature Modification:	0.00044
Barrier:	0.00043
Change in Avr Flows Summer-Autumn:	0.000231
Change in Min Flows Summer-Autumn:	0.000223
Change in Max Flows Winter-Spring:	0.000202
Change in Avr Flows Winter-Spring:	0.000198
Diverse Structural Habitat Descriptor:	0.000127
Floodplain Inundation:	0.000025
Connectivity:	0.000025
Potential Recruitment:	0.000017
Community Change:	0.000009
Current Abundance:	0.000005
pH:	0.000002
Turbidity:	0.000001
Native Riparian Veg.:	0.000001
Salinity:	0.000001
Snags:	0.000001
Anthropogenic Inputs:	0.000001
Dissolved Oxygen:	0.000001
Habitat Simplification, Aquatic Veg:	0
Current Diversity:	0
Site:	0
Alien Threat:	0
Loss of Fish:	0
Time_Scale:	0
Migratory spp.:	0
Macroinvertebrates, Zoobenthos:	0
Type:	0
Stocking Rate:	0
Non-Migratory spp.:	0

Future Diversity

Findings set: Site = G_Eildon

Entropy of Future Diversity:	0.221105
Future Abundance:	0.046391
Current Diversity:	0.019616
Water Quality Habitat Descriptor:	0.00261
Hydraulic Habitat Descriptor:	0.001074
Migratory spp.:	0.00025
Connectivity:	0.00014
Non-Migratory spp.:	0.000131
Barrier:	0.000112
Temperature Modification:	0.000107
Natives Biological Potential Descriptor:	0.000099
Change in Avr Flows Summer-Autumn:	0.000052
Change in Min Flows Summer-Autumn:	0.000051
Change in Max Flows Winter-Spring:	0.000047
Change in Avr Flows Winter-Spring:	0.000046
Stocking Rate:	0.000024
Diverse Structural Habitat Descriptor:	0.000017
Floodplain Inundation:	0.000004
Potential Recruitment:	0.000003
Community Change:	0.000001
Current Abundance:	0.000001
pH:	0
Native Riparian Veg.:	0
Anthropogenic Inputs:	0
Site:	0
Turbidity:	0
Snags:	0
Macroinvertebrates, Zoobenthos:	0
Alien Threat:	0
Habitat Simplification, Aquatic Veg:	0
Salinity:	0
Dissolved Oxygen:	0
Type:	0
Loss of Fish:	0
Time_Scale:	0

Findings set: Site = G_Alexandra

Entropy of Future Abundance:	0.395943
Future Diversity:	0.047878
Water Quality Habitat Descriptor:	0.020355
Hydraulic Habitat Descriptor:	0.009553
Temperature Modification:	0.002962
Barrier:	0.002945
Change in Avr Flows Summer-Autumn:	0.001532
Change in Min Flows Summer-Autumn:	0.001496
Change in Max Flows Winter-Spring:	0.001332
Change in Avr Flows Winter-Spring:	0.001304
Natives Biological Potential Descriptor:	0.000945
Connectivity:	0.000498
Potential Recruitment:	0.000284
Diverse Structural Habitat Descriptor:	0.000125
Floodplain Inundation:	0.000085
Community Change:	0.000008
Current Abundance:	0.000007
Native Riparian Veg.:	0.000004
Snags:	0.000003
Current Diversity:	0.000003
Salinity:	0.000002
Anthropogenic Inputs:	0.000002
Habitat Simplification, Aquatic Veg:	0.000001
Dissolved Oxygen:	0.000001
pH:	0.000001
Turbidity:	0
Stocking Rate:	0
Site:	0
Macroinvertebrates, Zoobenthos:	0
Alien Threat:	0
Migratory spp.:	0
Time_Scale:	0
Loss of Fish:	0
Type:	0
Non-Migratory spp.:	0

Findings set: Site = G_Alexandra

Entropy of Future Diversity:	0.226279
Future Abundance:	0.047878
Current Diversity:	0.020489
Water Quality Habitat Descriptor:	0.0031
Hydraulic Habitat Descriptor:	0.001308
Barrier:	0.000711
Temperature Modification:	0.000682
Connectivity:	0.000431
Migratory spp.:	0.000374
Change in Avr Flows Summer-Autumn:	0.000331
Change in Min Flows Summer-Autumn:	0.000325
Change in Max Flows Winter-Spring:	0.000292
Change in Avr Flows Winter-Spring:	0.000287
Non-Migratory spp.:	0.00014
Natives Biological Potential Descriptor:	0.000137
Stocking Rate:	0.000113
Potential Recruitment:	0.000053
Diverse Structural Habitat Descriptor:	0.000017
Floodplain Inundation:	0.000015
Community Change:	0.000001
Current Abundance:	0.000001
Native Riparian Veg.:	0
Snags:	0
Anthropogenic Inputs:	0
Salinity:	0
Habitat Simplification, Aquatic Veg:	0
Site:	0
pH:	0
Alien Threat:	0
Macroinvertebrates, Zoobenthos:	0
Loss of Fish:	0
Time_Scale:	0
Type:	0
Dissolved Oxygen:	0
Turbidity:	0

Findings set: Site = G_Yea

Entropy of Future Abundance:	0.458304
Future Diversity:	0.056762
Water Quality Habitat Descriptor:	0.025584
Hydraulic Habitat Descriptor:	0.016118
Temperature Modification:	0.003897
Barrier:	0.00389
Potential Recruitment:	0.002688
Change in Avr Flows Summer-Autumn:	0.00264
Natives Biological Potential Descriptor:	0.002435
Change in Avr Flows Winter-Spring:	0.001265
Connectivity:	0.000987
Change in Max Flows Winter-Spring:	0.000589
Turbidity:	0.000118
Change in Min Flows Summer-Autumn:	0.000072
Current Abundance:	0.000067
Diverse Structural Habitat Descriptor:	0.000034
Community Change:	0.000012
Current Diversity:	0.000008
Salinity:	0.000005
Anthropogenic Inputs:	0.000005
Macroinvertebrates, Zoobenthos:	0.000004
pH:	0.000002
Dissolved Oxygen:	0.000002
Habitat Simplification, Aquatic Veg:	0.000001
Stocking Rate:	0.000001
Floodplain Inundation:	0.000001
Alien Threat:	0
Loss of Fish:	0
Site:	0
Type:	0
Non-Migratory spp.:	0
Time_Scale:	0
Native Riparian Veg.:	0
Migratory spp.:	0
Snags:	0

Findings set: Site = G_Yea

Entropy of Future Diversity:	0.264508
Future Abundance:	0.056762
Current Diversity:	0.026725
Water Quality Habitat Descriptor:	0.004207
Hydraulic Habitat Descriptor:	0.002279
Migratory spp.:	0.001441
Barrier:	0.001194
Temperature Modification:	0.001092
Connectivity:	0.000848
Non-Migratory spp.:	0.000711
Change in Avr Flows Summer-Autumn:	0.000627
Potential Recruitment:	0.000429
Stocking Rate:	0.000401
Natives Biological Potential Descriptor:	0.000379
Change in Avr Flows Winter-Spring:	0.000351
Change in Max Flows Winter-Spring:	0.000083
Turbidity:	0.000019
Change in Min Flows Summer-Autumn:	0.000011
Current Abundance:	0.00001
Diverse Structural Habitat Descriptor:	0.000005
Community Change:	0.000002
Salinity:	0.000001
Anthropogenic Inputs:	0.000001
Macroinvertebrates, Zoobenthos:	0.000001
Dissolved Oxygen:	0
pH:	0
Floodplain Inundation:	0
Habitat Simplification, Aquatic Veg:	0
Site:	0
Snags:	0
Alien Threat:	0
Loss of Fish:	0
Type:	0
Native Riparian Veg.:	0
Time_Scale:	0

Findings set: Site = G_Trawool

Entropy of Future Abundance:	0.409637
Future Diversity:	0.050418
Water Quality Habitat Descriptor:	0.021039
Hydraulic Habitat Descriptor:	0.019745
Temperature Modification:	0.006847
Barrier:	0.006845
Change in Avr Flows Summer-Autumn:	0.004337
Change in Avr Flows Winter-Spring:	0.004196
Potential Recruitment:	0.00225
Connectivity:	0.001806
Natives Biological Potential Descriptor:	0.001796
Turbidity:	0.000196
Change in Max Flows Winter-Spring:	0.000092
Change in Min Flows Summer-Autumn:	0.000083
Current Abundance:	0.000055
Current Diversity:	0.000015
pH:	0.000013
Dissolved Oxygen:	0.000013
Salinity:	0.000009
Anthropogenic Inputs:	0.000009
Community Change:	0.000008
Diverse Structural Habitat Descriptor:	0.000007
Floodplain Inundation:	0.000003
Macroinvertebrates, Zoobenthos:	0.000003
Habitat Simplification, Aquatic Veg:	0.000001
Stocking Rate:	0.000001
Native Riparian Veg.:	0
Alien Threat:	0
Loss of Fish:	0
Migratory spp.:	0
Site:	0
Time_Scale:	0
Snags:	0
Type:	0
Non-Migratory spp.:	0

Findings set: Site = G_Trawool

Entropy of Future Diversity:	0.252718
Future Abundance:	0.050418
Current Diversity:	0.028496
Water Quality Habitat Descriptor:	0.003389
Hydraulic Habitat Descriptor:	0.002884
Barrier:	0.001814
Migratory spp.:	0.001782
Temperature Modification:	0.001689
Connectivity:	0.001176
Non-Migratory spp.:	0.000943
Change in Avr Flows Summer-Autumn:	0.000925
Change in Avr Flows Winter-Spring:	0.0009
Stocking Rate:	0.000483
Potential Recruitment:	0.000349
Natives Biological Potential Descriptor:	0.000272
Turbidity:	0.000029
Change in Max Flows Winter-Spring:	0.000013
Change in Min Flows Summer-Autumn:	0.000012
Current Abundance:	0.000008
pH:	0.000002
Dissolved Oxygen:	0.000002
Salinity:	0.000001
Anthropogenic Inputs:	0.000001
Community Change:	0.000001
Diverse Structural Habitat Descriptor:	0.000001
Macroinvertebrates, Zoobenthos:	0
Floodplain Inundation:	0
Habitat Simplification, Aquatic Veg:	0
Site:	0
Time_Scale:	0
Native Riparian Veg.:	0
Loss of Fish:	0
Type:	0
Alien Threat:	0
Snags:	0

Findings set: Site = Rubicon

Entropy of Future Abundance:	0.759404
Future Diversity:	0.09513
Water Quality Habitat Descriptor:	0.04808
Natives Biological Potential Descriptor:	0.025152
Turbidity:	0.01992
Potential Recruitment:	0.017899
Hydraulic Habitat Descriptor:	0.015228
Current Abundance:	0.004621
pH:	0.000682
Dissolved Oxygen:	0.000682
Barrier:	0.000349
Temperature Modification:	0.000347
Anthropogenic Inputs:	0.00034
Salinity:	0.00034
Diverse Structural Habitat Descriptor:	0.000339
Change in Min Flows Summer-Autumn:	0.000117
Change in Avr Flows Summer-Autumn:	0.000103
Change in Avr Flows Winter-Spring:	0.000074
Change in Max Flows Winter-Spring:	0.000065
Community Change:	0.00005
Floodplain Inundation:	0.000015
Native Riparian Veg.:	0.000011
Snags:	0.000009
Macroinvertebrates, Zoobenthos:	0.000007
Habitat Simplification, Aquatic Veg:	0.000003
Stocking Rate:	0.000001
Alien Threat:	0.000001
Migratory spp.:	0
Loss of Fish:	0
Site:	0
Type:	0
Connectivity:	0
Current Diversity:	0
Time_Scale:	0
Non-Migratory spp.:	0

Findings set: Site = Rubicon

Entropy of Future Diversity:	0.383237
Future Abundance:	0.09513
Current Diversity:	0.026325
Water Quality Habitat Descriptor:	0.007767
Natives Biological Potential Descriptor:	0.004099
Turbidity:	0.00325
Potential Recruitment:	0.002948
Hydraulic Habitat Descriptor:	0.002424
Connectivity:	0.000816
Current Abundance:	0.000764
Migratory spp.:	0.000285
pH:	0.000111
Dissolved Oxygen:	0.000111
Non-Migratory spp.:	0.000107
Barrier:	0.00009
Stocking Rate:	0.000089
Temperature Modification:	0.000065
Diverse Structural Habitat Descriptor:	0.000056
Salinity:	0.000055
Anthropogenic Inputs:	0.000055
Change in Min Flows Summer-Autumn:	0.000013
Change in Avr Flows Summer-Autumn:	0.000011
Community Change:	0.000008
Change in Max Flows Winter-Spring:	0.000008
Change in Avr Flows Winter-Spring:	0.000007
Floodplain Inundation:	0.000005
Native Riparian Veg.:	0.000002
Snags:	0.000001
Macroinvertebrates, Zoobenthos:	0.000001
Habitat Simplification, Aquatic Veg:	0
Site:	0
Alien Threat:	0
Type:	0
Loss of Fish:	0
Time_Scale:	0

Findings set: Site = Taggerty

Entropy of Future Abundance:	0.794233
Future Diversity:	0.099398
Natives Biological Potential Descriptor:	0.035037
Water Quality Habitat Descriptor:	0.023614
Hydraulic Habitat Descriptor:	0.021332
Current Abundance:	0.003582
Potential Recruitment:	0.002965
pH:	0.000935
Dissolved Oxygen:	0.000935
Turbidity:	0.000486
Salinity:	0.000475
Anthropogenic Inputs:	0.000472
Barrier:	0.000442
Temperature Modification:	0.000434
Community Change:	0.000407
Diverse Structural Habitat Descriptor:	0.000244
Change in Min Flows Summer-Autumn:	0.000212
Stocking Rate:	0.000135
Change in Avr Flows Summer-Autumn:	0.000106
Change in Max Flows Winter-Spring:	0.000078
Floodplain Inundation:	0.000073
Change in Avr Flows Winter-Spring:	0.000068
Alien Threat:	0.000035
Loss of Fish:	0.000022
Habitat Simplification, Aquatic Veg:	0.000008
Snags:	0.000007
Native Riparian Veg.:	0.000005
Macroinvertebrates, Zoobenthos:	0.000001
Connectivity:	0.000001
Migratory spp.:	0
Site:	0
Non-Migratory spp.:	0
Current Diversity:	0
Type:	0
Time_Scale:	0

Findings set: Site = Taggerty

Entropy of Future Diversity:	0.404293
Future Abundance:	0.099398
Current Diversity:	0.028074
Natives Biological Potential Descriptor:	0.005704
Water Quality Habitat Descriptor:	0.003839
Hydraulic Habitat Descriptor:	0.003429
Connectivity:	0.000838
Current Abundance:	0.000592
Migratory spp.:	0.00053
Potential Recruitment:	0.000502
pH:	0.000153
Dissolved Oxygen:	0.000153
Barrier:	0.000128
Non-Migratory spp.:	0.000126
Temperature Modification:	0.000081
Turbidity:	0.000079
Salinity:	0.000078
Anthropogenic Inputs:	0.000077
Community Change:	0.000068
Change in Min Flows Summer-Autumn:	0.000042
Diverse Structural Habitat Descriptor:	0.00004
Stocking Rate:	0.000032
Floodplain Inundation:	0.000018
Change in Avr Flows Summer-Autumn:	0.000017
Change in Max Flows Winter-Spring:	0.000016
Change in Avr Flows Winter-Spring:	0.00001
Alien Threat:	0.000006
Loss of Fish:	0.000004
Habitat Simplification, Aquatic Veg:	0.000001
Snags:	0.000001
Native Riparian Veg.:	0.000001
Macroinvertebrates, Zoobenthos:	0
Site:	0
Time_Scale:	0
Type:	0

Findings set: Site = Acheron

Entropy of Future Abundance:	0.774642
Future Diversity:	0.097241
Natives Biological Potential Descriptor:	0.049143
Water Quality Habitat Descriptor:	0.020176
Hydraulic Habitat Descriptor:	0.017013
Potential Recruitment:	0.003283
Current Abundance:	0.001744
Turbidity:	0.001647
Community Change:	0.000318
Floodplain Inundation:	0.000268
pH:	0.000252
Dissolved Oxygen:	0.000235
Diverse Structural Habitat Descriptor:	0.000185
Macroinvertebrates, Zoobenthos:	0.000174
Salinity:	0.00013
Anthropogenic Inputs:	0.00012
Temperature Modification:	0.000116
Barrier:	0.000111
Change in Avr Flows Summer-Autumn:	0.000029
Change in Min Flows Summer-Autumn:	0.000029
Change in Max Flows Winter-Spring:	0.000019
Change in Avr Flows Winter-Spring:	0.000019
Alien Threat:	0.000016
Loss of Fish:	0.000009
Stocking Rate:	0.000002
Habitat Simplification, Aquatic Veg:	0.000002
Snags:	0.000002
Native Riparian Veg.:	0.000001
Site:	0
Non-Migratory spp.:	0
Type:	0
Connectivity:	0
Current Diversity:	0
Migratory spp.:	0
Time_Scale:	0

Findings set: Site = Acheron

Entropy of Future Diversity:	0.395905
Future Abundance:	0.097241
Current Diversity:	0.028482
Natives Biological Potential Descriptor:	0.007895
Water Quality Habitat Descriptor:	0.003264
Hydraulic Habitat Descriptor:	0.002725
Connectivity:	0.000794
Migratory spp.:	0.000573
Potential Recruitment:	0.000545
Non-Migratory spp.:	0.00035
Current Abundance:	0.000287
Turbidity:	0.000269
Community Change:	0.000053
Floodplain Inundation:	0.000048
pH:	0.000041
Dissolved Oxygen:	0.000038
Stocking Rate:	0.000032
Barrier:	0.000031
Diverse Structural Habitat Descriptor:	0.000031
Macroinvertebrates, Zoobenthos:	0.000029
Temperature Modification:	0.000021
Salinity:	0.000021
Anthropogenic Inputs:	0.00002
Change in Max Flows Winter-Spring:	0.000004
Change in Avr Flows Summer-Autumn:	0.000004
Change in Min Flows Summer-Autumn:	0.000004
Alien Threat:	0.000003
Change in Avr Flows Winter-Spring:	0.000002
Loss of Fish:	0.000001
Habitat Simplification, Aquatic Veg:	0
Snags:	0
Native Riparian Veg.:	0
Site:	0
Type:	0
Time_Scale:	0

Findings set: Site = Murrindindi

Entropy of Future Abundance:	0.810592
Future Diversity:	0.101838
Natives Biological Potential Descriptor:	0.032764
Water Quality Habitat Descriptor:	0.022456
Hydraulic Habitat Descriptor:	0.019503
Potential Recruitment:	0.005636
Current Abundance:	0.003448
pH:	0.000348
Dissolved Oxygen:	0.000327
Diverse Structural Habitat Descriptor:	0.000205
Salinity:	0.000176
Turbidity:	0.000169
Anthropogenic Inputs:	0.000165
Temperature Modification:	0.000165
Barrier:	0.000161
Floodplain Inundation:	0.000127
Community Change:	0.000089
Change in Min Flows Summer-Autumn:	0.000046
Change in Avr Flows Summer-Autumn:	0.000044
Change in Avr Flows Winter-Spring:	0.000032
Change in Max Flows Winter-Spring:	0.000024
Alien Threat:	0.000009
Loss of Fish:	0.000007
Macroinvertebrates, Zoobenthos:	0.000001
Stocking Rate:	0.000001
Habitat Simplification, Aquatic Veg:	0
Snags:	0
Native Riparian Veg.:	0
Site:	0
Non-Migratory spp.:	0
Type:	0
Connectivity:	0
Current Diversity:	0
Migratory spp.:	0
Time_Scale:	0

Findings set: Site = Murrindindi

Entropy of Future Diversity:	0.421224
Future Abundance:	0.101838
Current Diversity:	0.031551
Natives Biological Potential Descriptor:	0.005315
Water Quality Habitat Descriptor:	0.003659
Hydraulic Habitat Descriptor:	0.003148
Migratory spp.:	0.000975
Potential Recruitment:	0.000938
Connectivity:	0.000793
Non-Migratory spp.:	0.000636
Current Abundance:	0.000566
pH:	0.000057
Dissolved Oxygen:	0.000054
Barrier:	0.000038
Diverse Structural Habitat Descriptor:	0.000034
Stocking Rate:	0.000034
Temperature Modification:	0.00003
Salinity:	0.000029
Turbidity:	0.000028
Anthropogenic Inputs:	0.000027
Floodplain Inundation:	0.000024
Community Change:	0.000015
Change in Min Flows Summer-Autumn:	0.000005
Change in Avr Flows Summer-Autumn:	0.000005
Change in Max Flows Winter-Spring:	0.000003
Change in Avr Flows Winter-Spring:	0.000003
Alien Threat:	0.000001
Loss of Fish:	0.000001
Macroinvertebrates, Zoobenthos:	0
Snags:	0
Site:	0
Habitat Simplification, Aquatic Veg:	0
Type:	0
Time_Scale:	0
Native Riparian Veg.:	0

Findings set: Site = Yea

Entropy of Future Abundance:	0.814304
Future Diversity:	0.10148
Natives Biological Potential Descriptor:	0.036907
Water Quality Habitat Descriptor:	0.02746
Hydraulic Habitat Descriptor:	0.020576
Potential Recruitment:	0.0088
Current Abundance:	0.004004
pH:	0.001142
Dissolved Oxygen:	0.001142
Turbidity:	0.000585
Salinity:	0.000573
Anthropogenic Inputs:	0.000572
Barrier:	0.000571
Temperature Modification:	0.000565
Diverse Structural Habitat Descriptor:	0.000336
Change in Min Flows Summer-Autumn:	0.000183
Change in Avr Flows Summer-Autumn:	0.000165
Community Change:	0.000154
Change in Avr Flows Winter-Spring:	0.000121
Change in Max Flows Winter-Spring:	0.000109
Alien Threat:	0.000013
Macroinvertebrates, Zoobenthos:	0.000009
Loss of Fish:	0.000009
Floodplain Inundation:	0.000005
Snags:	0.000002
Habitat Simplification, Aquatic Veg:	0.000002
Stocking Rate:	0.000001
Native Riparian Veg.:	0.000001
Site:	0
Time_Scale:	0
Type:	0
Connectivity:	0
Current Diversity:	0
Migratory spp.:	0
Non-Migratory spp.:	0

Findings set: Site = Yea

Entropy of Future Diversity:	0.413366
Future Abundance:	0.10148
Current Diversity:	0.02764
Natives Biological Potential Descriptor:	0.005929
Water Quality Habitat Descriptor:	0.004464
Hydraulic Habitat Descriptor:	0.003302
Potential Recruitment:	0.001448
Connectivity:	0.000836
Current Abundance:	0.000649
Migratory spp.:	0.000318
Dissolved Oxygen:	0.000187
pH:	0.000187
Barrier:	0.00013
Non-Migratory spp.:	0.00012
Temperature Modification:	0.000104
Turbidity:	0.000096
Salinity:	0.000094
Anthropogenic Inputs:	0.000094
Stocking Rate:	0.000083
Diverse Structural Habitat Descriptor:	0.000055
Community Change:	0.000026
Change in Min Flows Summer-Autumn:	0.00002
Change in Avr Flows Summer-Autumn:	0.000018
Change in Max Flows Winter-Spring:	0.000012
Change in Avr Flows Winter-Spring:	0.000012
Floodplain Inundation:	0.000003
Alien Threat:	0.000002
Macroinvertebrates, Zoobenthos:	0.000001
Loss of Fish:	0.000001
Snags:	0
Habitat Simplification, Aquatic Veg:	0
Native Riparian Veg.:	0
Site:	0
Time_Scale:	0
Type:	0

Findings set: Site = King Parrot

Entropy of Future Abundance:	0.817855
Future Diversity:	0.102816
Natives Biological Potential Descriptor:	0.042829
Water Quality Habitat Descriptor:	0.031915
Hydraulic Habitat Descriptor:	0.021579
Potential Recruitment:	0.011201
Current Abundance:	0.008363
pH:	0.001844
Dissolved Oxygen:	0.001844
Turbidity:	0.000939
Salinity:	0.00092
Anthropogenic Inputs:	0.00092
Barrier:	0.000899
Temperature Modification:	0.000894
Diverse Structural Habitat Descriptor:	0.000393
Change in Min Flows Summer-Autumn:	0.000305
Change in Avr Flows Summer-Autumn:	0.000258
Change in Avr Flows Winter-Spring:	0.000189
Change in Max Flows Winter-Spring:	0.000142
Community Change:	0.000108
Floodplain Inundation:	0.00004
Macroinvertebrates, Zoobenthos:	0.000019
Stocking Rate:	0.000005
Snags:	0.000004
Habitat Simplification, Aquatic Veg:	0.000004
Alien Threat:	0.000004
Loss of Fish:	0.000002
Native Riparian Veg.:	0.000002
Migratory spp.:	0.000001
Connectivity:	0
Site:	0
Type:	0
Current Diversity:	0
Non-Migratory spp.:	0
Time_Scale:	0

Findings set: Site = King Parrot

Entropy of Future Diversity:	0.426834
Future Abundance:	0.102816
Current Diversity:	0.032348
Natives Biological Potential Descriptor:	0.006954
Water Quality Habitat Descriptor:	0.005224
Hydraulic Habitat Descriptor:	0.003475
Potential Recruitment:	0.001859
Current Abundance:	0.001379
Non-Migratory spp.:	0.000944
Connectivity:	0.000848
Migratory spp.:	0.000727
pH:	0.000304
Dissolved Oxygen:	0.000304
Stocking Rate:	0.000234
Barrier:	0.00021
Temperature Modification:	0.000165
Turbidity:	0.000155
Salinity:	0.000152
Anthropogenic Inputs:	0.000152
Diverse Structural Habitat Descriptor:	0.000066
Change in Min Flows Summer-Autumn:	0.000035
Change in Avr Flows Summer-Autumn:	0.000029
Change in Max Flows Winter-Spring:	0.000019
Change in Avr Flows Winter-Spring:	0.000019
Community Change:	0.000018
Floodplain Inundation:	0.000014
Macroinvertebrates, Zoobenthos:	0.000003
Habitat Simplification, Aquatic Veg:	0.000001
Snags:	0.000001
Alien Threat:	0.000001
Loss of Fish:	0
Native Riparian Veg.:	0
Site:	0
Type:	0
Time_Scale:	0

Findings set: Site = Sunday

Entropy of Future Abundance:	0.647941
Future Diversity:	0.081976
Hydraulic Habitat Descriptor:	0.044998
Water Quality Habitat Descriptor:	0.027106
Natives Biological Potential Descriptor:	0.012528
Turbidity:	0.004308
pH:	0.003607
Potential Recruitment:	0.001558
Dissolved Oxygen:	0.001367
Current Abundance:	0.001132
Barrier:	0.000919
Salinity:	0.000681
Anthropogenic Inputs:	0.000679
Change in Min Flows Summer-Autumn:	0.000452
Temperature Modification:	0.000344
Change in Max Flows Winter-Spring:	0.000289
Change in Avr Flows Summer-Autumn:	0.000263
Change in Avr Flows Winter-Spring:	0.000191
Community Change:	0.000152
Floodplain Inundation:	0.000111
Connectivity:	0.000037
Diverse Structural Habitat Descriptor:	0.000033
Alien Threat:	0.000013
Loss of Fish:	0.000009
Stocking Rate:	0.000007
Migratory spp.:	0.000001
Current Diversity:	0.000001
Habitat Simplification, Aquatic Veg:	0.000001
Snags:	0.000001
Native Riparian Veg.:	0
Macroinvertebrates, Zoobenthos:	0
Site:	0
Non-Migratory spp.:	0
Type:	0
Time_Scale:	0

Findings set: Site = Sunday

Entropy of Future Diversity:	0.341444
Future Abundance:	0.081975
Current Diversity:	0.028831
Hydraulic Habitat Descriptor:	0.007138
Water Quality Habitat Descriptor:	0.004246
Natives Biological Potential Descriptor:	0.002133
Migratory spp.:	0.000987
Connectivity:	0.000956
Turbidity:	0.000676
pH:	0.000566
Non-Migratory spp.:	0.000464
Barrier:	0.000395
Potential Recruitment:	0.000294
Stocking Rate:	0.000282
Dissolved Oxygen:	0.000214
Current Abundance:	0.000186
Change in Min Flows Summer-Autumn:	0.000133
Salinity:	0.000107
Anthropogenic Inputs:	0.000106
Change in Avr Flows Summer-Autumn:	0.000091
Change in Max Flows Winter-Spring:	0.00008
Temperature Modification:	0.000072
Change in Avr Flows Winter-Spring:	0.000057
Floodplain Inundation:	0.000037
Community Change:	0.000025
Diverse Structural Habitat Descriptor:	0.000005
Alien Threat:	0.000002
Loss of Fish:	0.000001
Snags:	0
Site:	0
Time_Scale:	0
Macroinvertebrates, Zoobenthos:	0
Type:	0
Habitat Simplification, Aquatic Veg:	0
Native Riparian Veg.:	0

Findings set: Site = Hughes

Entropy of Future Abundance:	0.746965
Future Diversity:	0.094048
Water Quality Habitat Descriptor:	0.070463
Natives Biological Potential Descriptor:	0.033516
Potential Recruitment:	0.030084
Hydraulic Habitat Descriptor:	0.016754
Turbidity:	0.014206
Salinity:	0.014055
Current Abundance:	0.005229
pH:	0.001207
Dissolved Oxygen:	0.001207
Barrier:	0.000682
Temperature Modification:	0.00064
Anthropogenic Inputs:	0.000604
Change in Min Flows Summer-Autumn:	0.000375
Change in Avr Flows Summer-Autumn:	0.000295
Diverse Structural Habitat Descriptor:	0.000225
Change in Avr Flows Winter-Spring:	0.000221
Change in Max Flows Winter-Spring:	0.000207
Community Change:	0.000085
Macroinvertebrates, Zoobenthos:	0.00003
Floodplain Inundation:	0.000009
Native Riparian Veg.:	0.000004
Habitat Simplification, Aquatic Veg:	0.000003
Stocking Rate:	0.000002
Loss of Fish:	0.000001
Alien Threat:	0.000001
Snags:	0
Connectivity:	0
Site:	0
Migratory spp.:	0
Type:	0
Current Diversity:	0
Time_Scale:	0
Non-Migratory spp.:	0

Findings set: Site = Hughes

Entropy of Future Diversity:	0.383972
Future Abundance:	0.094048
Current Diversity:	0.02881
Water Quality Habitat Descriptor:	0.011464
Natives Biological Potential Descriptor:	0.005507
Potential Recruitment:	0.004956
Hydraulic Habitat Descriptor:	0.002621
Turbidity:	0.00233
Salinity:	0.002306
Current Abundance:	0.000868
Connectivity:	0.000811
Migratory spp.:	0.000741
Non-Migratory spp.:	0.000319
pH:	0.000197
Dissolved Oxygen:	0.000197
Stocking Rate:	0.000187
Barrier:	0.000178
Temperature Modification:	0.000124
Anthropogenic Inputs:	0.000099
Change in Min Flows Summer-Autumn:	0.000042
Diverse Structural Habitat Descriptor:	0.000037
Change in Avr Flows Summer-Autumn:	0.000031
Change in Max Flows Winter-Spring:	0.000022
Change in Avr Flows Winter-Spring:	0.000021
Community Change:	0.000014
Macroinvertebrates, Zoobenthos:	0.000005
Native Riparian Veg.:	0.000001
Habitat Simplification, Aquatic Veg:	0
Loss of Fish:	0
Alien Threat:	0
Floodplain Inundation:	0
Site:	0
Type:	0
Time_Scale:	0
Snags:	0

Findings set: Site = G_Lk_Nagambie

Entropy of Future Abundance:	0.813818
Future Diversity:	0.104447
Natives Biological Potential Descriptor:	0.038961
Water Quality Habitat Descriptor:	0.032862
Hydraulic Habitat Descriptor:	0.017363
Current Abundance:	0.004037
Potential Recruitment:	0.003224
pH:	0.002135
Dissolved Oxygen:	0.002135
Turbidity:	0.001096
Salinity:	0.001073
Anthropogenic Inputs:	0.001068
Temperature Modification:	0.001044
Barrier:	0.001044
Change in Avr Flows Winter-Spring:	0.000413
Community Change:	0.000394
Change in Max Flows Winter-Spring:	0.000368
Change in Min Flows Summer-Autumn:	0.000364
Floodplain Inundation:	0.000315
Change in Avr Flows Summer-Autumn:	0.000309
Diverse Structural Habitat Descriptor:	0.000067
Macroinvertebrates, Zoobenthos:	0.000043
Stocking Rate:	0.000008
Alien Threat:	0.000006
Habitat Simplification, Aquatic Veg:	0.000004
Snags:	0.000003
Connectivity:	0.000003
Native Riparian Veg.:	0.000003
Loss of Fish:	0.000002
Migratory spp.:	0
Site:	0
Non-Migratory spp.:	0
Current Diversity:	0
Type:	0
Time_Scale:	0

Findings set: Site = G_Lk_Nagambie

Entropy of Future Diversity:	0.447413
Future Abundance:	0.104447
Current Diversity:	0.041007
Natives Biological Potential Descriptor:	0.006544
Water Quality Habitat Descriptor:	0.00544
Migratory spp.:	0.00352
Non-Migratory spp.:	0.002973
Hydraulic Habitat Descriptor:	0.00281
Current Abundance:	0.000685
Potential Recruitment:	0.000567
pH:	0.000357
Dissolved Oxygen:	0.000357
Stocking Rate:	0.000294
Barrier:	0.000233
Turbidity:	0.000183
Salinity:	0.000179
Anthropogenic Inputs:	0.000179
Temperature Modification:	0.000176
Connectivity:	0.000148
Community Change:	0.000067
Floodplain Inundation:	0.000062
Change in Min Flows Summer-Autumn:	0.000056
Change in Avr Flows Winter-Spring:	0.000041
Change in Max Flows Winter-Spring:	0.000039
Change in Avr Flows Summer-Autumn:	0.000033
Diverse Structural Habitat Descriptor:	0.000011
Macroinvertebrates, Zoobenthos:	0.000007
Alien Threat:	0.000001
Habitat Simplification, Aquatic Veg:	0.000001
Snags:	0.000001
Native Riparian Veg.:	0
Loss of Fish:	0
Site:	0
Type:	0
Time_Scale:	0

Findings set: Site = G_Murchison

Entropy of Future Abundance:	0.816604
Future Diversity:	0.118981
Natives Biological Potential Descriptor:	0.059051
Water Quality Habitat Descriptor:	0.048888
Potential Recruitment:	0.023849
Hydraulic Habitat Descriptor:	0.019449
Current Abundance:	0.004887
pH:	0.00448
Dissolved Oxygen:	0.004479
Barrier:	0.002303
Turbidity:	0.002255
Salinity:	0.002207
Anthropogenic Inputs:	0.002206
Temperature Modification:	0.002091
Connectivity:	0.001118
Change in Min Flows Summer-Autumn:	0.001067
Change in Avr Flows Summer-Autumn:	0.000983
Change in Avr Flows Winter-Spring:	0.000936
Change in Max Flows Winter-Spring:	0.000845
Community Change:	0.000149
Diverse Structural Habitat Descriptor:	0.000138
Macroinvertebrates, Zoobenthos:	0.000059
Floodplain Inundation:	0.000057
Habitat Simplification, Aquatic Veg:	0.000014
Current Diversity:	0.000004
Native Riparian Veg.:	0.000002
Snags:	0.000002
Alien Threat:	0.000001
Loss of Fish:	0.000001
Stocking Rate:	0
Site:	0
Type:	0
Time_Scale:	0
Non-Migratory spp.:	0
Migratory spp.:	0

Findings set: Site = G_Murchison

Entropy of Future Diversity:	0.547212
Future Abundance:	0.118981
Current Diversity:	0.073199
Natives Biological Potential Descriptor:	0.01121
Water Quality Habitat Descriptor:	0.009181
Potential Recruitment:	0.004805
Hydraulic Habitat Descriptor:	0.003684
Migratory spp.:	0.002561
Non-Migratory spp.:	0.001676
Barrier:	0.001217
Connectivity:	0.001095
Current Abundance:	0.000938
pH:	0.000827
Dissolved Oxygen:	0.000827
Temperature Modification:	0.000807
Change in Min Flows Summer-Autumn:	0.000489
Change in Avr Flows Summer-Autumn:	0.000454
Change in Avr Flows Winter-Spring:	0.00044
Turbidity:	0.000416
Change in Max Flows Winter-Spring:	0.000408
Salinity:	0.000407
Anthropogenic Inputs:	0.000407
Stocking Rate:	0.000045
Community Change:	0.000029
Diverse Structural Habitat Descriptor:	0.000026
Macroinvertebrates, Zoobenthos:	0.000011
Habitat Simplification, Aquatic Veg:	0.000003
Floodplain Inundation:	0.000002
Snags:	0
Native Riparian Veg.:	0
Loss of Fish:	0
Alien Threat:	0
Site:	0
Time_Scale:	0
Type:	0

Findings set: Site = G_Shepparton

Entropy of Future Abundance:	0.854421
Future Diversity:	0.148537
Water Quality Habitat Descriptor:	0.037892
Natives Biological Potential Descriptor:	0.036804
Hydraulic Habitat Descriptor:	0.017012
pH:	0.002264
Dissolved Oxygen:	0.002264
Barrier:	0.001432
Temperature Modification:	0.001226
Turbidity:	0.001157
Salinity:	0.001133
Anthropogenic Inputs:	0.001131
Potential Recruitment:	0.001062
Change in Max Flows Winter-Spring:	0.000898
Change in Avr Flows Winter-Spring:	0.000841
Connectivity:	0.000656
Change in Avr Flows Summer-Autumn:	0.000579
Change in Min Flows Summer-Autumn:	0.000563
Community Change:	0.000515
Floodplain Inundation:	0.000431
Current Abundance:	0.000408
Diverse Structural Habitat Descriptor:	0.000047
Stocking Rate:	0.000012
Macroinvertebrates, Zoobenthos:	0.000007
Alien Threat:	0.000005
Snags:	0.000003
Loss of Fish:	0.000001
Current Diversity:	0.000001
Habitat Simplification, Aquatic Veg:	0
Site:	0
Non-Migratory spp.:	0
Type:	0
Time_Scale:	0
Migratory spp.:	0
Native Riparian Veg.:	0

Findings set: Site = G_Shepparton

Entropy of Future Diversity:	0.676217
Future Abundance:	0.148537
Current Diversity:	0.097278
Non-Migratory spp.:	0.014104
Migratory spp.:	0.009789
Natives Biological Potential Descriptor:	0.00837
Water Quality Habitat Descriptor:	0.008223
Hydraulic Habitat Descriptor:	0.003712
Barrier:	0.000686
Connectivity:	0.000597
pH:	0.000491
Dissolved Oxygen:	0.000491
Temperature Modification:	0.000456
Change in Max Flows Winter-Spring:	0.000371
Change in Avr Flows Winter-Spring:	0.000351
Change in Avr Flows Summer-Autumn:	0.000263
Turbidity:	0.000251
Change in Min Flows Summer-Autumn:	0.000251
Salinity:	0.000246
Anthropogenic Inputs:	0.000245
Potential Recruitment:	0.000229
Community Change:	0.000117
Floodplain Inundation:	0.000111
Current Abundance:	0.000093
Stocking Rate:	0.000038
Diverse Structural Habitat Descriptor:	0.000011
Macroinvertebrates, Zoobenthos:	0.000002
Alien Threat:	0.000001
Snags:	0.000001
Loss of Fish:	0
Site:	0
Habitat Simplification, Aquatic Veg:	0
Type:	0
Time_Scale:	0
Native Riparian Veg.:	0

Findings set: Site = G_McCoy

Entropy of Future Abundance:	0.887039
Future Diversity:	0.13863
Natives Biological Potential Descriptor:	0.043579
Water Quality Habitat Descriptor:	0.031146
Hydraulic Habitat Descriptor:	0.015561
Current Abundance:	0.00261
Potential Recruitment:	0.00209
Community Change:	0.000456
Floodplain Inundation:	0.00034
Salinity:	0.000248
Dissolved Oxygen:	0.00015
pH:	0.00015
Turbidity:	0.000103
Barrier:	0.00009
Temperature Modification:	0.000082
Anthropogenic Inputs:	0.000075
Diverse Structural Habitat Descriptor:	0.000069
Change in Max Flows Winter-Spring:	0.000056
Change in Avr Flows Winter-Spring:	0.000053
Change in Avr Flows Summer-Autumn:	0.000035
Change in Min Flows Summer-Autumn:	0.000033
Connectivity:	0.000006
Alien Threat:	0.000003
Stocking Rate:	0.000001
Site:	0
Native Riparian Veg.:	0
Time_Scale:	0
Habitat Simplification, Aquatic Veg:	0
Snags:	0
Macroinvertebrates, Zoobenthos:	0
Type:	0
Loss of Fish:	0
Current Diversity:	0
Migratory spp.:	0
Non-Migratory spp.:	0

Findings set: Site = G_McCoy

Entropy of Future Diversity:	0.641495
Future Abundance:	0.13863
Current Diversity:	0.09088
Natives Biological Potential Descriptor:	0.00887
Migratory spp.:	0.006812
Water Quality Habitat Descriptor:	0.006158
Non-Migratory spp.:	0.005203
Hydraulic Habitat Descriptor:	0.00306
Current Abundance:	0.000539
Potential Recruitment:	0.00043
Connectivity:	0.000107
Community Change:	0.000094
Floodplain Inundation:	0.000071
Salinity:	0.00005
Barrier:	0.000044
pH:	0.00003
Dissolved Oxygen:	0.00003
Temperature Modification:	0.00003
Stocking Rate:	0.000024
Change in Max Flows Winter-Spring:	0.000023
Change in Avr Flows Winter-Spring:	0.000022
Turbidity:	0.000021
Change in Avr Flows Summer-Autumn:	0.000016
Anthropogenic Inputs:	0.000015
Change in Min Flows Summer-Autumn:	0.000014
Diverse Structural Habitat Descriptor:	0.000014
Alien Threat:	0.000001
Site:	0
Habitat Simplification, Aquatic Veg:	0
Loss of Fish:	0
Macroinvertebrates, Zoobenthos:	0
Native Riparian Veg.:	0
Type:	0
Time_Scale:	0
Snags:	0

Findings set: Site = G_Undera

Entropy of Future Abundance:	0.772837
Future Diversity:	0.113455
Water Quality Habitat Descriptor:	0.07425
Natives Biological Potential Descriptor:	0.022228
Turbidity:	0.022212
Hydraulic Habitat Descriptor:	0.018047
Potential Recruitment:	0.00767
pH:	0.003609
Dissolved Oxygen:	0.003609
Barrier:	0.002267
Temperature Modification:	0.002024
Salinity:	0.001745
Anthropogenic Inputs:	0.001744
Current Abundance:	0.001665
Change in Max Flows Winter-Spring:	0.00149
Change in Avr Flows Winter-Spring:	0.001415
Connectivity:	0.001206
Change in Min Flows Summer-Autumn:	0.000945
Change in Avr Flows Summer-Autumn:	0.000944
Floodplain Inundation:	0.000299
Community Change:	0.000113
Diverse Structural Habitat Descriptor:	0.00007
Current Diversity:	0.000008
Stocking Rate:	0.000007
Macroinvertebrates, Zoobenthos:	0.000006
Native Riparian Veg.:	0.000002
Alien Threat:	0.000002
Habitat Simplification, Aquatic Veg:	0.000002
Loss of Fish:	0.000002
Migratory spp.:	0.000001
Snags:	0
Site:	0
Non-Migratory spp.:	0
Type:	0
Time_Scale:	0

Findings set: Site = G_Undera

Entropy of Future Diversity:	0.52645
Future Abundance:	0.113455
Current Diversity:	0.071714
Water Quality Habitat Descriptor:	0.013977
Natives Biological Potential Descriptor:	0.004306
Turbidity:	0.004143
Hydraulic Habitat Descriptor:	0.00359
Non-Migratory spp.:	0.00356
Migratory spp.:	0.003083
Barrier:	0.00155
Connectivity:	0.001467
Potential Recruitment:	0.00135
Temperature Modification:	0.000945
Stocking Rate:	0.000856
Change in Max Flows Winter-Spring:	0.000741
Change in Avr Flows Winter-Spring:	0.000708
pH:	0.000666
Dissolved Oxygen:	0.000666
Change in Avr Flows Summer-Autumn:	0.000533
Change in Min Flows Summer-Autumn:	0.000456
Salinity:	0.000322
Anthropogenic Inputs:	0.000322
Current Abundance:	0.000316
Floodplain Inundation:	0.000094
Community Change:	0.000022
Diverse Structural Habitat Descriptor:	0.000013
Macroinvertebrates, Zoobenthos:	0.000001
Native Riparian Veg.:	0
Alien Threat:	0
Loss of Fish:	0
Habitat Simplification, Aquatic Veg:	0
Site:	0
Type:	0
Snags:	0
Time_Scale:	0

Findings set: Site = G_Echuca

Entropy of Future Abundance:	0.685065
Future Diversity:	0.111689
Water Quality Habitat Descriptor:	0.064057
Hydraulic Habitat Descriptor:	0.0133
Turbidity:	0.008988
Salinity:	0.008862
Natives Biological Potential Descriptor:	0.008491
Potential Recruitment:	0.002167
pH:	0.001926
Dissolved Oxygen:	0.001926
Barrier:	0.00153
Temperature Modification:	0.00123
Change in Max Flows Winter-Spring:	0.001179
Change in Avr Flows Winter-Spring:	0.001133
Connectivity:	0.000994
Anthropogenic Inputs:	0.000928
Change in Avr Flows Summer-Autumn:	0.000807
Change in Min Flows Summer-Autumn:	0.000796
Current Abundance:	0.000352
Floodplain Inundation:	0.000129
Community Change:	0.000089
Diverse Structural Habitat Descriptor:	0.000032
Stocking Rate:	0.000008
Current Diversity:	0.000006
Macroinvertebrates, Zoobenthos:	0.000004
Native Riparian Veg.:	0.000001
Habitat Simplification, Aquatic Veg:	0.000001
Alien Threat:	0.000001
Loss of Fish:	0.000001
Migratory spp.:	0
Snags:	0
Site:	0
Time_Scale:	0
Non-Migratory spp.:	0
Type:	0

Findings set: Site = G_Echuca

Entropy of Future Diversity:	0.553972
Future Abundance:	0.111689
Current Diversity:	0.080687
Water Quality Habitat Descriptor:	0.012836
Non-Migratory spp.:	0.009615
Migratory spp.:	0.008377
Hydraulic Habitat Descriptor:	0.002758
Natives Biological Potential Descriptor:	0.001783
Turbidity:	0.001755
Salinity:	0.001731
Barrier:	0.001284
Connectivity:	0.00126
Temperature Modification:	0.000691
Change in Max Flows Winter-Spring:	0.00062
Change in Avr Flows Winter-Spring:	0.000599
Change in Avr Flows Summer-Autumn:	0.000473
Change in Min Flows Summer-Autumn:	0.000455
Potential Recruitment:	0.000401
pH:	0.000371
Dissolved Oxygen:	0.000371
Stocking Rate:	0.000262
Anthropogenic Inputs:	0.000178
Current Abundance:	0.00007
Floodplain Inundation:	0.000054
Community Change:	0.000018
Diverse Structural Habitat Descriptor:	0.000006
Macroinvertebrates, Zoobenthos:	0.000001
Native Riparian Veg.:	0
Habitat Simplification, Aquatic Veg:	0
Site:	0
Loss of Fish:	0
Snags:	0
Type:	0
Time_Scale:	0
Alien Threat:	0

Findings set: Site = Pranjip

Entropy of Future Abundance:	0.768412
Future Diversity:	0.099724
Water Quality Habitat Descriptor:	0.063991
Natives Biological Potential Descriptor:	0.032079
Turbidity:	0.02462
Hydraulic Habitat Descriptor:	0.018402
Potential Recruitment:	0.017184
Current Abundance:	0.004955
pH:	0.00206
Dissolved Oxygen:	0.00206
Barrier:	0.001095
Temperature Modification:	0.00106
Salinity:	0.001013
Anthropogenic Inputs:	0.001012
Diverse Structural Habitat Descriptor:	0.00071
Macroinvertebrates, Zoobenthos:	0.000524
Change in Min Flows Summer-Autumn:	0.000432
Change in Avr Flows Summer-Autumn:	0.000384
Change in Avr Flows Winter-Spring:	0.000287
Change in Max Flows Winter-Spring:	0.00026
Community Change:	0.000181
Alien Threat:	0.000042
Snags:	0.000014
Habitat Simplification, Aquatic Veg:	0.000013
Native Riparian Veg.:	0.000009
Floodplain Inundation:	0.000008
Stocking Rate:	0.000004
Loss of Fish:	0.000001
Site:	0
Type:	0
Migratory spp.:	0
Connectivity:	0
Current Diversity:	0
Non-Migratory spp.:	0
Time_Scale:	0

Findings set: Site = Pranjip

Entropy of Future Diversity:	0.431212
Future Abundance:	0.099724
Current Diversity:	0.042688
Water Quality Habitat Descriptor:	0.010647
Natives Biological Potential Descriptor:	0.005468
Turbidity:	0.00414
Hydraulic Habitat Descriptor:	0.002948
Potential Recruitment:	0.00293
Non-Migratory spp.:	0.002787
Migratory spp.:	0.002396
Current Abundance:	0.000846
Connectivity:	0.000816
Stocking Rate:	0.00062
pH:	0.000344
Dissolved Oxygen:	0.000344
Barrier:	0.000274
Temperature Modification:	0.000204
Salinity:	0.000169
Anthropogenic Inputs:	0.000169
Diverse Structural Habitat Descriptor:	0.000121
Macroinvertebrates, Zoobenthos:	0.000089
Change in Min Flows Summer-Autumn:	0.00005
Change in Avr Flows Summer-Autumn:	0.000042
Community Change:	0.000031
Change in Max Flows Winter-Spring:	0.000029
Change in Avr Flows Winter-Spring:	0.000029
Alien Threat:	0.000007
Snags:	0.000002
Habitat Simplification, Aquatic Veg:	0.000002
Native Riparian Veg.:	0.000002
Floodplain Inundation:	0
Loss of Fish:	0
Site:	0
Type:	0
Time_Scale:	0

Findings set: Site = Creightons_Brankeet

Entropy of Future Abundance:	0.681454
Future Diversity:	0.087079
Water Quality Habitat Descriptor:	0.058658
Potential Recruitment:	0.022359
Natives Biological Potential Descriptor:	0.020184
Hydraulic Habitat Descriptor:	0.012328
Turbidity:	0.011168
Salinity:	0.010985
Current Abundance:	0.002469
pH:	0.000515
Dissolved Oxygen:	0.000515
Barrier:	0.000318
Temperature Modification:	0.000298
Anthropogenic Inputs:	0.000257
Change in Min Flows Summer-Autumn:	0.000187
Change in Avr Flows Summer-Autumn:	0.000169
Diverse Structural Habitat Descriptor:	0.000159
Change in Avr Flows Winter-Spring:	0.000125
Change in Max Flows Winter-Spring:	0.000103
Community Change:	0.000036
Macroinvertebrates, Zoobenthos:	0.000008
Native Riparian Veg.:	0.000004
Floodplain Inundation:	0.000003
Stocking Rate:	0.000002
Snags:	0.000001
Loss of Fish:	0.000001
Migratory spp.:	0
Alien Threat:	0
Site:	0
Non-Migratory spp.:	0
Time_Scale:	0
Connectivity:	0
Current Diversity:	0
Habitat Simplification, Aquatic Veg:	0
Type:	0

Findings set: Site = Creightons_Brankeet

Entropy of Future Diversity:	0.371779
Future Abundance:	0.087079
Current Diversity:	0.034701
Water Quality Habitat Descriptor:	0.009556
Potential Recruitment:	0.0037
Natives Biological Potential Descriptor:	0.003396
Hydraulic Habitat Descriptor:	0.001879
Non-Migratory spp.:	0.001833
Turbidity:	0.001823
Salinity:	0.001793
Migratory spp.:	0.001214
Connectivity:	0.000784
Current Abundance:	0.000411
Stocking Rate:	0.000372
Barrier:	0.000109
pH:	0.000083
Dissolved Oxygen:	0.000083
Temperature Modification:	0.000061
Anthropogenic Inputs:	0.000042
Diverse Structural Habitat Descriptor:	0.000026
Change in Min Flows Summer-Autumn:	0.000019
Change in Avr Flows Summer-Autumn:	0.000017
Change in Max Flows Winter-Spring:	0.000012
Change in Avr Flows Winter-Spring:	0.000011
Community Change:	0.000006
Floodplain Inundation:	0.000004
Macroinvertebrates, Zoobenthos:	0.000001
Native Riparian Veg.:	0.000001
Snags:	0
Site:	0
Habitat Simplification, Aquatic Veg:	0
Loss of Fish:	0
Type:	0
Alien Threat:	0
Time_Scale:	0

Findings set: Site = Castle

Entropy of Future Abundance:	0.804034
Future Diversity:	0.101463
Natives Biological Potential Descriptor:	0.043467
Water Quality Habitat Descriptor:	0.043463
Hydraulic Habitat Descriptor:	0.022573
Potential Recruitment:	0.016523
Current Abundance:	0.008521
pH:	0.004005
Dissolved Oxygen:	0.004005
Turbidity:	0.002009
Anthropogenic Inputs:	0.001968
Salinity:	0.001967
Barrier:	0.00193
Temperature Modification:	0.001903
Change in Min Flows Summer-Autumn:	0.000709
Change in Avr Flows Summer-Autumn:	0.000582
Diverse Structural Habitat Descriptor:	0.000486
Change in Avr Flows Winter-Spring:	0.000434
Change in Max Flows Winter-Spring:	0.000332
Community Change:	0.000124
Macroinvertebrates, Zoobenthos:	0.000051
Stocking Rate:	0.000012
Snags:	0.000012
Habitat Simplification, Aquatic Veg:	0.000012
Alien Threat:	0.000009
Native Riparian Veg.:	0.000008
Loss of Fish:	0.000005
Migratory spp.:	0.000003
Floodplain Inundation:	0.000001
Connectivity:	0
Current Diversity:	0
Site:	0
Type:	0
Non-Migratory spp.:	0
Time_Scale:	0

Findings set: Site = Castle

Entropy of Future Diversity:	0.421313
Future Abundance:	0.101463
Current Diversity:	0.032919
Natives Biological Potential Descriptor:	0.007149
Water Quality Habitat Descriptor:	0.007137
Hydraulic Habitat Descriptor:	0.003604
Potential Recruitment:	0.002743
Current Abundance:	0.001416
Migratory spp.:	0.001297
Connectivity:	0.00087
pH:	0.000661
Dissolved Oxygen:	0.000661
Non-Migratory spp.:	0.00061
Barrier:	0.000455
Stocking Rate:	0.000401
Temperature Modification:	0.000357
Turbidity:	0.000331
Anthropogenic Inputs:	0.000325
Salinity:	0.000325
Change in Min Flows Summer-Autumn:	0.000083
Diverse Structural Habitat Descriptor:	0.000081
Change in Avr Flows Summer-Autumn:	0.000065
Change in Avr Flows Winter-Spring:	0.000044
Change in Max Flows Winter-Spring:	0.000042
Community Change:	0.000021
Macroinvertebrates, Zoobenthos:	0.000009
Floodplain Inundation:	0.000006
Snags:	0.000002
Habitat Simplification, Aquatic Veg:	0.000002
Alien Threat:	0.000001
Native Riparian Veg.:	0.000001
Loss of Fish:	0.000001
Site:	0
Type:	0
Time_Scale:	0

Findings set: Site = Sevens

Entropy of Future Abundance:	0.887377
Future Diversity:	0.119124
Water Quality Habitat Descriptor:	0.046663
Natives Biological Potential Descriptor:	0.033668
Hydraulic Habitat Descriptor:	0.018157
Turbidity:	0.009189
Potential Recruitment:	0.004364
Current Abundance:	0.003848
pH:	0.001292
Dissolved Oxygen:	0.001292
Barrier:	0.000737
Temperature Modification:	0.00068
Anthropogenic Inputs:	0.000645
Salinity:	0.000644
Change in Max Flows Winter-Spring:	0.000439
Change in Avr Flows Winter-Spring:	0.000423
Community Change:	0.0003
Change in Avr Flows Summer-Autumn:	0.000259
Diverse Structural Habitat Descriptor:	0.000259
Change in Min Flows Summer-Autumn:	0.000251
Floodplain Inundation:	0.00023
Alien Threat:	0.000022
Loss of Fish:	0.000012
Stocking Rate:	0.000002
Snags:	0.000002
Habitat Simplification, Aquatic Veg:	0.000001
Macroinvertebrates, Zoobenthos:	0.000001
Native Riparian Veg.:	0.000001
Connectivity:	0
Site:	0
Time_Scale:	0
Non-Migratory spp.:	0
Current Diversity:	0
Migratory spp.:	0
Type:	0

Findings set: Site = Sevens

Entropy of Future Diversity:	0.541437
Future Abundance:	0.119124
Current Diversity:	0.061857
Water Quality Habitat Descriptor:	0.008138
Migratory spp.:	0.007171
Non-Migratory spp.:	0.00628
Natives Biological Potential Descriptor:	0.005914
Hydraulic Habitat Descriptor:	0.003129
Turbidity:	0.001623
Potential Recruitment:	0.000783
Current Abundance:	0.000684
Connectivity:	0.000675
Dissolved Oxygen:	0.000228
pH:	0.000228
Barrier:	0.000141
Temperature Modification:	0.000128
Anthropogenic Inputs:	0.000114
Salinity:	0.000114
Stocking Rate:	0.000061
Change in Max Flows Winter-Spring:	0.000059
Change in Avr Flows Winter-Spring:	0.000057
Community Change:	0.000053
Diverse Structural Habitat Descriptor:	0.000046
Floodplain Inundation:	0.00004
Change in Min Flows Summer-Autumn:	0.000037
Change in Avr Flows Summer-Autumn:	0.000033
Alien Threat:	0.000004
Loss of Fish:	0.000002
Habitat Simplification, Aquatic Veg:	0
Snags:	0
Native Riparian Veg.:	0
Macroinvertebrates, Zoobenthos:	0
Site:	0
Type:	0
Time_Scale:	0

APPENDIX 4

PREDICTIVE ACCURACY

```
For Turb:       Turbidity
--------

Confusion:
  .......Predicted......
     Low  Medium    High    Actual
  ------  ------  ------    ------
     215       0       2    Low
       0       0       0    Medium
       0       0       0    High

Error rate = 0.9217%

Scoring Rule Results:
  Logarithmic loss = 0.03518
  Quadratic loss   = 0.01023
  Spherical payoff = 0.9938
```

```
For Salinity:       Salinity
------------

Confusion:
  .......Predicted......
     Low  Medium    High    Actual
  ------  ------  ------    ------
     268       0       0    Low
       0       0       0    Medium
       0       0       0    High

Error rate = 0%

Scoring Rule Results:
  Logarithmic loss = 0.01425
  Quadratic loss   = 0.0007848
  Spherical payoff = 0.9998
```

```
For pH:       pH
------

Confusion:
  .......Predicted......
  alkali  neutra  acidic    Actual
  ------  ------  ------    ------
       0       0       0    alkaline
       0     364       0    neutral
       0       0       0    acidic

Error rate = 0%

Scoring Rule Results:
  Logarithmic loss = 0.01294
  Quadratic loss   = 0.0009451
  Spherical payoff = 0.9998
```

```
For DO:       Dissolved Oxygen
------

Confusion:
  .......Predicted......
  Extrem  Normal  Extrem    Actual
  ------  ------  ------    ------
       0       0       0    ExtremeLow
       0     374       0    Normal
       0       0       0    ExtremeHigh

Error rate = 0%
```

```
Scoring Rule Results:
  Logarithmic loss = 0.01054
  Quadratic loss   = 0.0006887
  Spherical payoff = 0.9999
```

```
For Toxicants:       Anthropogenic Inputs
-------------

Confusion:
  .......Predicted......
     Low  Medium    High    Actual
  ------  ------  ------    ------
     374       0       0    Low
       0       0       0    Medium
       0       0       0    High

Error rate = 0%

Scoring Rule Results:
  Logarithmic loss = 0.01056
  Quadratic loss   = 0.0006898
  Spherical payoff = 0.9999
```

```
For Temp:       Temperature Modification
--------

Confusion:
  .......Predicted......
  NoChan  Modera   Major    Actual
  ------  ------  ------    ------
     327       0       0    NoChange
       2       0       0    Moderate
       0       0      48    Major

Error rate = 0.5305%

Scoring Rule Results:
  Logarithmic loss = 0.03408
  Quadratic loss   = 0.01057
  Spherical payoff = 0.9947
```

```
For Barrier:       Barrier
-----------

Confusion:
  ..........Predicted.........
      No  Innund  Comple  Comple    Actual
  ------  ------  ------  ------    ------
     133       0       2       0    No
       0     134       0       0    Innundated
       0       0      60       0    CompleteShallow
       0       0       0      51    CompleteDeep

Error rate = 0.5263%

Scoring Rule Results:
  Logarithmic loss = 0.01839
  Quadratic loss   = 0.009609
  Spherical payoff = 0.995
```

```
For AvrSummer:       Change in Avr Flows Summer-Aut
-------------

Confusion:
  ..............Predicted.............
  ExtDec  Decrea  NoChan  Increa  ExtInc    Actual
  ------  ------  ------  ------  ------    ------
     119       0       0       0       0    ExtDecrease
       0       3       0       0      13    Decrease
       2       0       0       0       8    NoChange
       0       0       0     146       2    Increase
```

```
       0       0       0       0      71    ExtIncrease

Error rate = 6.868%

Scoring Rule Results:
  Logarithmic loss = 0.1647
  Quadratic loss   = 0.08663
  Spherical payoff = 0.9452
```

```
For AvrWinter:       Change in Avr Flows Winter-Spr
-------------

Confusion:
  ...............Predicted.............
  ExtDec  Decrea  NoChan  Increa  ExtInc    Actual
  ------  ------  ------  ------  ------    ------
     129       0      11       0       0    ExtDecrease
       0      55       8       0       0    Decrease
       2       0     159       0       0    NoChange
       0       0       0       0       0    Increase
       0       0       0       0       0    ExtIncrease

Error rate = 5.769%

Scoring Rule Results:
  Logarithmic loss = 0.1389
  Quadratic loss   = 0.07704
  Spherical payoff = 0.9534
-------------------------------------------------------
For MinSummer:       Change in Min Flows Summer-Aut
-------------

Confusion:
  ...............Predicted.............
  ExtDec  Decrea  NoChan  Increa  ExtInc    Actual
  ------  ------  ------  ------  ------    ------
     119       0       0       0       0    ExtDecrease
       0       3       0       0      13    Decrease
       2       0       0       0       5    NoChange
       0       0       0     146       2    Increase
       0       0       0       0      68    ExtIncrease

Error rate = 6.145%

Scoring Rule Results:
  Logarithmic loss = 0.148
  Quadratic loss   = 0.07719
  Spherical payoff = 0.9525
```

```
For MaxWinter:       Change in Max Flows Winter-Spr
-------------

Confusion:
  ...............Predicted.............
  ExtDec  Decrea  NoChan  Increa  ExtInc    Actual
  ------  ------  ------  ------  ------    ------
     126       0      11       0       0    ExtDecrease
       0      55       8       0       0    Decrease
       2       0     156       0       0    NoChange
       0       0       0       0       0    Increase
       0       0       0       0       0    ExtIncrease

Error rate = 5.866%

Scoring Rule Results:
  Logarithmic loss = 0.1347
  Quadratic loss   = 0.07518
  Spherical payoff = 0.9541
```

```
For Snags:       Snags
---------
```

```
Confusion:
  .......Predicted......
     Low  Medium    High    Actual
  ------  ------  ------    ------
     186       0       8    Low
       0      85      34    Medium
       0       0      63    High

Error rate = 11.17%

Scoring Rule Results:
  Logarithmic loss = 0.17
  Quadratic loss   = 0.09859
  Spherical payoff = 0.9395
For HabSimp:       Habitat Simplification, Aquati
-----------

Confusion:
  .......Predicted......
  Comple    Some    None    Actual
  ------  ------  ------    ------
       0       0       0    Complete
       0     263      30    Some
       0       0      83    None

Error rate = 7.979%

Scoring Rule Results:
  Logarithmic loss = 0.1294
  Quadratic loss   = 0.08846
  Spherical payoff = 0.9479
-------------------------------------------------------For
Riparian:       Native Riparian  Veg.
------------

Confusion:
  .......Predicted......
  Degrad  Modera  Intact    Actual
  ------  ------  ------    ------
     141       5       0    Degraded
       0     217       0    Moderate
       0      13       0    Intact

Error rate = 4.787%

Scoring Rule Results:
  Logarithmic loss = 0.136
  Quadratic loss   = 0.07352
  Spherical payoff = 0.9579
-------------------------------------------------------For
Food:       Macroinvertebrates, Zoobenthos
--------

Confusion:
  .......Predicted......
     Low  Medium    High    Actual
  ------  ------  ------    ------
       0       0       0    Low
       0       0       2    Medium
       0       0     313    High

Error rate = 0.6349%

Scoring Rule Results:
  Logarithmic loss = 0.03982
  Quadratic loss   = 0.01412
  Spherical payoff = 0.9932
```

```
-------------------------------------------------------For
PopStat:       Current Abundance
-----------

Confusion:
  ...Predicted..
     Low    High    Actual
  ------  ------    ------
     158       0    Low
      14       0    High

Error rate = 8.14%

Scoring Rule Results:
  Logarithmic loss = 0.2577
  Quadratic loss   = 0.1496
  Spherical payoff = 0.9196
-------------------------------------------------------For
Fishing:       Loss of Fish
-----------

Confusion:
  ...Predicted..
     Low    High    Actual
  ------  ------    ------
       3       0    Low
       0     233    High

Error rate = 0%

Scoring Rule Results:
  Logarithmic loss = 0.007355
  Quadratic loss   = 0.0005323
  Spherical payoff = 0.9998
-------------------------------------------------------For
Aliens:       Alien Threat
----------

Confusion:
  ...Predicted..
     Yes      No    Actual
  ------  ------    ------
     114       5    Yes
      44       9    No

Error rate = 28.49%

Scoring Rule Results:
  Logarithmic loss = 0.6015
  Quadratic loss   = 0.403
  Spherical payoff = 0.7725
-------------------------------------------------------For
NonMig:       Non-Migratory spp.
----------

Confusion:
  ...Predicted..
     Low    High    Actual
  ------  ------    ------
     160       1    Low
      11       0    High

Error rate = 6.977%

Scoring Rule Results:
  Logarithmic loss = 0.2004
  Quadratic loss   = 0.1107
  Spherical payoff = 0.9402
```

```
-------------------------------------------------------For
Stocking:       Stocking Rate
------------

Confusion:
  .......Predicted......
    None     Low    High    Actual
  ------  ------  ------    ------
     156      13       0    None
       0     190       0    Low
       0       0       0    High

Error rate = 3.621%

Scoring Rule Results:
  Logarithmic loss = 0.0878
  Quadratic loss   = 0.0564
  Spherical payoff = 0.9681
-------------------------------------------------------For
Migspp:       Migratory spp.
----------

Confusion:
  ...Predicted..
     Low    High    Actual
  ------  ------    ------
     166       0    Low
       6       0    High

Error rate = 3.488%

Scoring Rule Results:
  Logarithmic loss = 0.09024
  Quadratic loss   = 0.04624
  Spherical payoff = 0.9748
-------------------------------------------------------For
Site:
--------

Error rate = 3.421%

Scoring Rule Results:
  Logarithmic loss = 0.1463
  Quadratic loss   = 0.09369
  Spherical payoff = 0.9484
-------------------------------------------------------For
Time_Scale:
--------------

Confusion:
  ...Predicted..
  One_ye  Five_y    Actual
  ------  ------    ------
      96      85    One_year
     109      90    Five_year

Error rate = 51.05%

Scoring Rule Results:
  Logarithmic loss = 0.6926
  Quadratic loss   = 0.4995
  Spherical payoff = 0.7075
-------------------------------------------------------For
FutureAbundance:       Future Abundance
-------------------

Confusion:
  ...Predicted..
```

```
     Low    High    Actual
  ------  ------    ------
      25       0    Low
       3       0    High

Error rate = 10.71%

Scoring Rule Results:
  Logarithmic loss = 0.3127
  Quadratic loss   = 0.1833
  Spherical payoff = 0.9014
-------------------------------------------------------For
FutureDiversity:       Future Diversity
-------------------

Confusion:
  ...Predicted..
     Low    High    Actual
  ------  ------    ------
      28       0    Low
       0       0    High

Error rate = 0%

Scoring Rule Results:
  Logarithmic loss = 0.06208
  Quadratic loss   = 0.02321
  Spherical payoff = 0.9894
-------------------------------------------------------
```