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Fish communities and threatened species distributions of NSW

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Fish Communities and Threatened Species Distributions of NSW

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Executive non-technical summary

Fish and fish habitat underpins the productivity of our State's fisheries resources. Fish habitat conservation and management also contributes to the NSW Government's 10 year plan NSW 2021 (see 2021.nsw.gov.au/) which aims to protect our natural environment, including its rivers, wetlands and coastal environments. Fish habitats are not discrete systems but are elements of larger 'open' aquatic systems that are often interconnected by water flow, floods, tides, currents, and the movement of biota, chemicals and nutrients within the water column.

There are over 1000 species of fish in NSW and tens of thousands of species of crustaceans, aquatic molluscs, beachworms, aquatic insects and other aquatic invertebrates – all of which are classified as 'fish' under the *Fisheries Management Act 1994.* NSW has an estimated 118 species of freshwater fish, including native (57 species), introduced (17), and estuarine vagrant (31) and as yet undescribed (13) species. A number of fish species, populations and ecological communities are listed as 'threatened', with primary causes due to the degradation of our river systems and the loss of aquatic habitat.

A major issue facing the NSW Government is finding a balance between resource use and the protection of the natural environment. In order to achieve that outcome, the delineation and spatial recognition of key environmental assets is paramount. Whilst spatial identification of natural resource use potential (i.e. forests, coal resources) has been well documented, the identification of aquatic biodiversity is not, and yet it is critical to the NSW Government's ability to deliver evidence based decision making.

The Fish Communities and Threatened Species Distributions of NSW project (FCTSD) consolidates data collected over twenty years of biological surveys, and combined with standard statistical analysis and internationally recognised spatial distribution models, provides a delineation and spatial recognition of the status of fish communities and threatened species distributions across NSW. The FCTSD project presents:

- An analysis of fish community data across NSW;
- spatial representation of the status of fish communities across NSW, including threatened species distributions; and
- supporting data to inform strategic planning frameworks to ensure they effectively integrate aquatic biodiversity considerations into planning and decision making processes.

The condition of fish communities is derived from the three condition indicators of Expectedness, Nativeness and Recruitment built from a number of NSW Department of Primary Industries Fisheries (DPI Fisheries) datasets. The indicators and the overall fish condition metric from sampled reaches were analysed using general additive modelling (GAM) to infer scores for all unsampled reaches using a suite of environmental variables extracted from the National Hydrological Geospatial Fabric Version 2 environmental attribute tables (NHGFV 2). Outcomes rate the condition of fish communities as Very Good, Good, Moderate, Poor, or Very Poor.

Indicative threatened species distributions were modelled using records, over the last 20 years, for most listed species from NSW DPI Fisheries data, museum collections and published literature. The distribution of listed threatened species was modelled using the presence-only species distribution modelling program MaxEnt and NHGFV 2 environmental variables.

The information from the FCTSD will form a critical input into ongoing strategic planning and assessment work including regional land use, water and natural resource planning across NSW. The FCTSD will assist planners and natural resource managers by providing:

- A robust and defendable baseline for future biodiversity planning and assessment by combining data analysis and modelling;
- an understanding of the state and natural variation of fish communities across NSW; and
- data to allow the effective integration of aquatic biodiversity considerations into planning processes.

Filling knowledge gaps on species distributions and improving spatially predictive models will enhance resource management decisions, by providing a greater understanding and appreciation of species distributions across catchments, regions and the state. The spatial products derived from this project should be used to guide and strengthen regional planning endeavours by ensuring that aquatic biodiversity values are recognised, considered and conserved in their regional and state context.

The revised indicative threatened species distributions are now also presented at a scale useful for regional and site based planning and assessment programs and represent either the last remaining areas of known presence of those species, or river reaches that have a similar suite of environmental variables suitable for those species. These latter river reaches could represent unsampled reaches where the species occurs, or areas of viable habitat that could support conservation stockings of threatened species.

The project represents the first time that this type of innovative analysis has been undertaken across NSW and it is planned to be the first of a series of assessments that will assist in the management, conservation and recovery efforts for fish biodiversity across NSW.

1. Introduction

Fish habitat underpins the productivity of our State's fisheries resources. The conservation and management of fish habitat also contributes to the NSW Government's 10 year plan, NSW 2021 (see: Targets associated with Goal 22 of the NSW 2021 Plan) which aims to protect our natural environment, including its rivers, wetlands and coastal environments.

There are over 1,000 species of fish in NSW and tens of thousands of species of crustaceans, aquatic molluscs, beachworms, aquatic insects and other aquatic invertebrates – all of which are classified as 'fish' under the *Fisheries Management Act 1994.*

NSW has an estimated 118 species of freshwater fish, including native (57 species), introduced (17), estuarine vagrant (31) and as yet undescribed (13) species. Of these, approximately 70 are native fish that spend the majority of their lifecycle in freshwater. Due to the degradation of our river systems and the loss of aquatic habitat, aquatic biodiversity has been declining since European settlement. To date 35 species of fish (fresh and marine), populations and ecological communities have been listed as 'threatened'.

The NSW Rivers Survey (Harris and Gehrke, 1997) studied the distribution, diversity and abundance of native fishes in NSW Rivers in 1994-1996. The survey recorded only 39 native fish species at 80 sites sampled across NSW, whereas earlier surveys in 1969-1970 had recorded an additional 9 species not detected during the NSW Rivers Survey (Llewellyn 1974).This work, as well as subsequent research (Morris *et al*. 2001) highlights the need for greater conservation efforts for many of the freshwater species occurring in NSW. The main causes of decline in freshwater fishes include habitat degradation due to various forms of water pollution, catchment development and land use-related activities, changes to water flow regimes, barriers to fish passage, the introduction of alien fish species and pathogens, thermal pollution and historical overfishing.

Fish habitats are not discrete units but are elements of larger and hierarchical 'open' aquatic systems that are often connected by water flow, floods, tides, currents, and the movement of biota, chemicals and nutrients within the water column. Many fish are reliant on a variety of different habitat types throughout their life cycle and as such, connectivity with a diverse range of habitats is a critical component to managing the states fisheries resources. This includes longitudinal connectivity, allowing fish to travel up and down waterways, lateral connectivity that allows fish to use wetlands and floodplains that connect different habitat areas and vertical connectivity within a system to enable fish to access habitat at different levels within a waterway (Fisheries NSW, 2013).

A major issue facing the NSW Government is finding a balance between resource use and the protection of the natural environment. In order to achieve that outcome, the delineation and spatial recognition of key environmental assets is paramount. Whilst spatial identification of natural resource use potential (i.e. forest, coal resources) has been well documented, the identification of aquatic biodiversity is not as well documented and is critical to the NSW Government's ability to deliver evidence based decision making.

Aquatic resource managers are often faced with a lack of information on the condition and distribution of the biological components of management areas. Maps of species distributions are often incomplete, outdated or non-existent (Joy and Death, 2004). This means that decisions regarding resource-use, even those with potential small or modest impacts, are often made in the absence of even basic information. Even modest impacts on stream ecosystems can have cumulative effects and therefore can contribute to a large impact (Joy and Death, 2004). By filling the knowledge gaps on distributions and by improving spatially predictive models, resource management decisions will improve by having a greater understanding and appreciation of condition and species distributions across catchments, regions and the state.

The FCTSD project consolidates data collected over the past twenty (20) years of biological surveys by the DPI Fisheries and other collectors, applying statistical analyses and spatial distribution modelling to provide a delineation and spatial recognition of the status of freshwater fish communities and threatened species across NSW.

This information will form a critical input into ongoing regional assessment work and for strategic land use planning by combining data analysis and modelling to form a robust and defendable baseline for future biodiversity planning and assessment. Further, the results of this project will more broadly assist natural resource managers and planners to understand the state and natural variation of fish communities across NSW, while providing additional support to strategic planning frameworks that can then effectively integrate aquatic biodiversity considerations into planning processes. This will then ensure that aquatic biodiversity objectives and priorities are considered early in planning and assessment processes.

1.1 Background

The Fish Communities and Threatened Species Distributions of NSW project (FCTSD) was funded via the National Partnership Agreement on Coal Seam Gas and Large Coal Mining Developments.

The National Partnership Agreement on Coal Seam Gas and Large Coal Mining Developments came into effect on 14 February 2012. In signing the Agreement, the Commonwealth and NSW Governments, sought to address public concerns about the actual and potential impacts of coal seam gas and coal mining activities on environmental resources, and agreed there is a critical need to strengthen the science that underpins the regulation of these industries.

The agreement aimed to substantially improve the scientific evidence that informs regulatory decisions; enhance the transparency and openness of regulatory processes; and ensure that independent expert advice on all relevant project proposals is available to communities, governments and industry. The funds were allocated to assist the Strategic Regional Land Use process, including supporting the Minister for Primary Industries to develop advice on aquifer impacts and ongoing regional assessment work in support of the Strategic Regional Land Use Plans (SRLUPs). The NSW Government is now preparing strategic land-use plans across NSW to provide greater certainty for the community, industry and stakeholders.

Within the strategic regional planning process, key regional challenges include:

- Identifying and protecting strategic regional conservation priorities and maximising the retention of areas of high value terrestrial and aquatic biodiversity;
- developing and applying appropriate measures to control, mitigate and regulate the impacts of mining activities (including cumulative impacts) on the environment; and
- identifying opportunities to preserve and, where possible, reconnect both terrestrial and aquatic habitats and corridors.

1.2 Aim of this report

The aim of this report is to outline the data used, methods of analysis, predictive modelling and spatial techniques applied in the development of the FCTSD project and derived spatial products. As with all projects of this nature there are limitations with data, methods and accuracy. It is important that end users have a clear understanding of the data, methods and techniques used, particularly the statistical analysis of large data sets and the limitations and assumptions that have been accepted and/or adopted.

The FCTSD project objectives were to:

- Carry out an analysis of fish community data across NSW;
- spatially represent the status of fish communities across NSW, including threatened species distributions; and
- provide additional support to strategic planning frameworks to ensure they effectively integrate aquatic (fish) biodiversity considerations into planning and decision making processes.

2 Methods

To ensure the aims and objectives of the project were achieved, and given the multi-disciplinary approach being taken, it was paramount that a steering committee be established to guide the project, ensure project objectives were achievable and relevant, that up to date data was acquired and reviewed, that a peer review process was followed, and opportunities for linkages and synergies with other strategic assessment processes were identified and considered.

2.1 Project steering committee

The FCTSD project steering committee included staff from the DPI Fisheries and Water division's research, evaluation and management units, including specialist Geographic Information Systems (GIS) analysts.

The steering committee's terms of reference included:

- Providing guidance and direction on the project scope, ensuring that the objectives are achievable within the timeframe and budget constraints;
- assisting with access to relevant data required to meet the objectives of the project;
- peer reviewing project reports to ensure consistency with project scope and objectives; and
- assessing opportunities for linkages and synergies to other strategic assessment and planning work so that this work value adds with other State processes (e.g. bioregional assessments, water sharing planning, catchment action planning, land use planning etc.).

The project team undertook a review of existing research, models, programs and frameworks that were relevant to the aims and objectives of spatially representing the status of freshwater fish communities and aquatic threatened species distributions across NSW. Broadly, GIS techniques were used to create the final mapped products. ESRI ArcGIS 10.2 with various extensions was used for the preparation, manipulation and spatial analysis of the data. Figure 1 illustrates a summarised workflow framework for the project.

Given the complexities associated with species data, environmental data, the desired spatial scale of final outputs, GIS constraints and project constraints (funding and time) the steering committee decided that two different approaches were required to determine and depict the general fish community status and threatened species distributions across NSW.

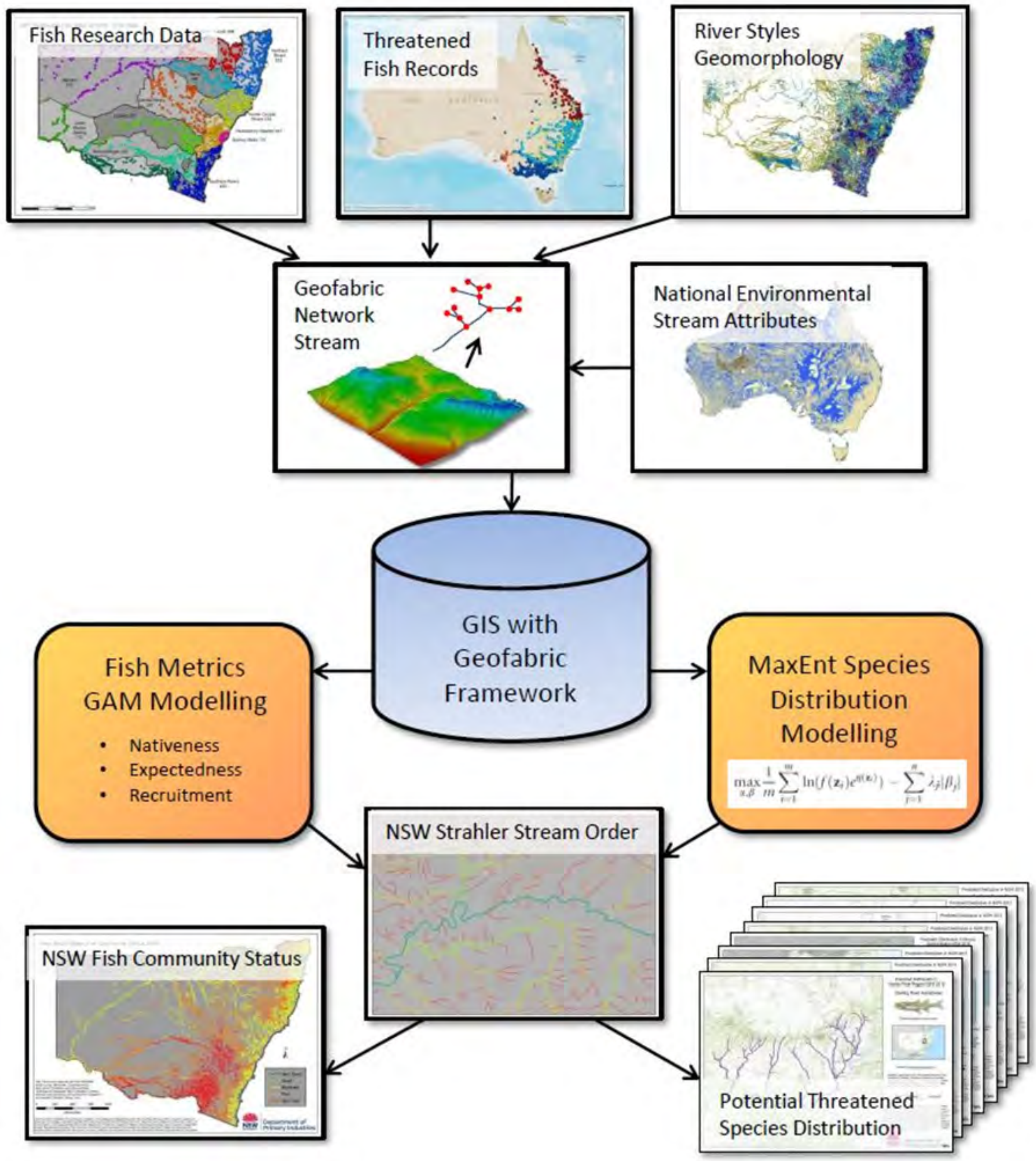

Figure 1 - Summarised project work flow framework

2.2 Primary data acquisition

2.2.1 NSW freshwater fish database

The NSW Freshwater Fish Research Database collates data from approximately 3,000 sites spread across all major drainage basins in NSW sampled by the DPI Fisheries over the last 20 years. Data includes physical and environmental variables, sampling methods, sampling effort, catch data and biological measurements from individual fish. Data used for this project was extracted from the master copy of this database dated 29 April 2013.

2.2.2 Threatened fish records

Records of the collection of each threatened freshwater aquatic species (both fish and invertebrates) listed under the *Fisheries Management Act 1994* (Table 1) were obtained from the following range of sources:

- Sampled locations for all threatened species were extracted from DPI Fisheries Freshwater Fish Research database (NSW DPI, 2013), AquaSee (NSW DPI Fisheries 'AquaSee database') and the DPI Fisheries Fish Kill database;
- data requests for all available records for each species were submitted to each of the Australian Museum, Museum Victoria, South Australian Museum and the Queensland Museum;
- a data request for all fish records from the Sustainable Rivers Audit (SRA) (including the pilot program) was submitted to the Murray-Darling Basin Authority in August 2013, the data provided covered all sampling periods from the SRA pilot, including the final implementation period. This equates to approximately 10+years of fish sampling data;
- the Atlas of Living Australia (www.ala.org.au) was queried for all available records of each species on 3 Sep 2014;
- filed raw datasheets from unpublished projects of past and current DPI Fisheries biologists were also accessed;
- section 37 (*Fisheries Management Act*) scientific permit sampling reports submitted to DPI Fisheries by external researchers were also utilised; and
- sampling records provided to and filed by the project team by external biologists were utilised, including data from: NSW Office of Environment and Heritage, Australian Crayfish project, Monash University and Charles Sturt University.

All sources provided sampling location as a set of spatial coordinates. Sampling records reported in relevant peer–reviewed literature, technical reports or student theses were also utilised. Sampling location was extracted from these published sources as coordinates if they were reported directly, or coordinates were inferred from maps provided in the publications if they were of sufficient spatial resolution to be certain that the coordinates inferred fell in the appropriate spatial stream segment.

Every record was carefully scrutinised to omit any spatial inaccuracies or species mis-identifications. Where any doubt existed about the veracity of the record, that record was omitted from analyses.

Table 1 Records were collected for the following freshwater species or populations listed as threatened under the *Fisheries Management Act 1994*.

Species	Threatened status (*Fisheries Management Act 1994*)
Olive Perchlet (*Ambassis agassizii*)	Endangered population (Western)
Silver Perch (*Bidyanus bidyanus*)	Vulnerable
Darling River Hardyhead (*Craterocephalus amniculus*)	Endangered population (Hunter River catchment)
Murray Hardyhead (*Craterocephalus fluviatilis*)	Critically endangered
Murray Crayfish (*Euastacus armatus*)	Vulnerable
Fitzroy Falls Spiny Crayfish (*Euastacus dharawalus*)	Critically endangered
River Blackfish (*Gadopsis marmoratus*)	Endangered population (Snowy River catchment)
Flat-headed Galaxias (*Galaxias rostratus*)	Critically endangered
Macquarie Perch (*Macquaria australasica*)	Endangered
Eastern Cod (*Maccullochella ikei*)	Endangered
Trout Cod (*Maccullochella macquariensis*)	Endangered
Southern Purple-spotted Gudgeon (*Mogurnda adspersa*)	Endangered
Southern Pygmy Perch (*Nannoperca australis*)	Endangered
Oxleyan Pygmy Perch (*Nannoperca oxleyana*)	Endangered
Freshwater Catfish (*Tandanus tandanus*)	Endangered population (Murray-Darling Basin)
Australian Grayling (*Prototrocetes marena*)	Endangered

2.2.3 River Styles

River Styles® is a geomorphic approach for examining river character, behaviour, condition and recovery potential (Brierley and Fryirs 2005). It is based on a set of procedures for classifying river character within a nested hierarchy of criteria based on valley setting, channel planform, geomorphic units, and bed material. DPI Water has compiled a spatial dataset of River Styles® classifications for a large number of the waterways of NSW: RiverStyles.gdb (Brierley et al. 2011, Healey et al. 2012). We accessed a version of RiverStyles.gdb from DPI Water dated 16/05/2008 and utilised the field labelled 'RIVER_STYLE_CODE_AND_DESC', consisting of 65 River Style® categories. These River Style® categories were broken down into Planform and Substratum groups as per the code description to aid analysis and interpretation.

2.2.4 Australian Hydrological Geospatial Fabric (Geofabric)

The Australian Hydrological Geospatial Fabric (http://www.bom.gov.au/water/geofabric/) (Geofabric) provides a framework for querying, reporting and modelling water information. It is a specialist geographical information system (GIS) platform that registers the spatial relationships between important hydrological features such as rivers, water bodies, aquifers and monitoring points. The Geofabric Surface Network contains a representation of the major surface water features of Australia. It portrays the flow direction of streams over the surface of the terrain, based on the GEODATA Nine Second Digital Elevation Model (DEM-9S) Version 3. Spatially, nine seconds is approximately 250 metres. The Geofabric Surface Network can support the spatial selection of associated hydrological features as inputs for spatial analysis/modelling. It allocates a unique stream segment number to each river reach in Australia. The Geofabric data used in this project was Geofabric SH Network GDB V2.1 downloaded from the Bureau of Meteorology (BOM).

2.2.5 National Environmental Stream Attributes

The Environmental Attributes Database (Stein et al. 2012) is a set of lookup tables supplying attributes describing the natural and anthropogenic characteristics of the stream and catchment environment that was developed by the Australian National University (ANU) in 2011. The data is supplied as part of the supplementary Geofabric products, which is associated with the 9 second DEM derived streams and the National Catchment Boundaries based on 250k scale stream network. A total of 910 environmental attribute variables are available, 18 attributes were used for this project. (see Appendix C).

2.2.6 NSW Strahler Stream Order

This product was developed by DPI Water in 2013 from the NSW Hydro Line 2012. The NSW Hydro Line is a line feature class of the NSW Digital Topographic Database (DTDB), within the Hydrography theme and has a positional accuracy within the range of 1m - 100m. The water course centrelines were stratified into Strahler Stream Order (Strahler 1957) using the RivEX tool (version 10.3) within ArcGIS10.1.

2.3 Fish assemblage status indicators

A suite of fish assemblage condition metrics, indicators and indexes were developed for reporting on river health under the Murray-Darling Basin Authority's Sustainable Rivers Audit (SRA) program (MDBC 2004, Davies et al 2008, Davies et al. 2010, Davies et al. 2012). The NSW Monitoring Evaluation and Reporting Riverine Ecosystems theme (Muschal et al. 2010) and reported in NSW State of the Environment reports (http://www.epa.nsw.gov.au/soe/) built upon the SRA framework by applying the same design principles, but collecting data from coastal and far-west catchments in order to provide a consistent state-wide freshwater fish monitoring and reporting program.

Sampling is based on a standardised SRA electrofishing and bait-trap protocol, with sampling intensity and methodological refinements derived from an extensive pilot exercise in 2002/03 (MDBC 2004). Fish assemblage data utilised for this report was collected from 646 sampling locations within the South-East Coast, Murray-Darling Basin, Bulloo and Lake Eyre Basin drainage divisions of NSW collected between January 2009 and December 2012. This represented the most recent three year sampling round where entire state-wide coverage was achieved. For coastal catchments the sampling framework was consistent with that developed for the SRA, but with some minor modifications necessary for application in coastal catchments, including an additional altitude zone for generating metrics in coastal catchments and amended site densities per valley, as well as the inclusion of impounded waters and more intensive sample processing procedures (see Muschal et al. 2010 for details).

Each fish assemblage sample location was assigned to a geofabric number (SEGMENTNO) using the same process described for threatened species records.

For estuarine fish assemblages the Estuarine Fish Community Index (EFCI) has been used as described in Roper et al (2011). The EFCI is a multi-metric index that combines the four broad fish community attributes of species diversity and composition, species abundance, nursery function, and trophic integrity into a single measure of estuarine condition.

2.3.1 Metrics indicators and overall fish community status index

Using the methods described by Robinson (2012), eight fish metrics were derived from the data collected at each site. The eight metrics were then aggregated to produce three fish condition indicators (Expectedness, Nativeness, Recruitment) and these indicators were then used to derive an overall Fish Condition Index (SRA ndxFS). Metric and indicator aggregation was done using Expert Rules analysis in the Fuzzy Logic toolbox of MatLab (The Mathworks Inc. USA) using the rules sets developed by Davies et al. (2010).

The Expectedness Indicator (SR-FIe) represents the proportion of native species that are now found within the basin, compared to that which was historically present. The Expectedness Indicator is derived from two input metrics; the observed native species richness over the expected species richness at each site (OE), and the total native species richness observed within the zone over the total number of species predicted to have existed within the zone historically (OP) (Robinson 2012). The expected and predicted pre-European fish community within each altitude band within each catchment was derived using the Reference Condition for Fish (RC-F) approach used by the SRA and NSW MER programs. The RC-F process involves using available historical and contemporary data, museum collections and expert knowledge to estimate the probability of collecting each species at any randomly selected site within an altitude zone if it were sampled using the standard sampling protocol prior to 1770 (Davies et al. 2008). Estuarine/marine vagrants were allocated an arbitrary RC-F probability of capture of 0.05, rare species (collected at 0 < 0.2 of samples) an RC-F of 0.1, occasional species (collected at 0.21 < 0.7 of samples) an RC-F of 0.45 and common species (collected at 0.71 < 1.0 samples) an RC-F of 0.85 (RC-F scores being the median capture probability within each category). The two metrics were aggregated using the Expectedness Indicator Expert Rule set (Carter 2012).

The Nativeness Indicator (SR-FIn) represents the proportion of native versus alien fishes. The Nativeness Indicator is derived from three input metrics; proportion native biomass, proportion native abundance and proportion native species (Robison 2012). The three metrics were aggregated using the Nativeness Indicator Expert Rule set (Carter 2012).

The Recruitment Indicator (SR-FIr) represents the recent reproductive activity of the native fish community within each altitude zone. The Recruitment Indicator is derived from three input metrics; the proportion of native species showing evidence of recruitment at a minimum of one site within a zone, the average proportion of sites within a zone at which each species captured was recruiting (RC-F corrected), and the average proportion of total abundance of each species that are new recruits (Robinson 2012). For large bodied and generally longer living species (> three years), an individual was considered to be a recruit if its body length was less than that of a one year old of the same species. For small bodied and generally short lived species that reach sexual maturity in under 1 year, the definition of ‘recruits’ for the MER program and this report differ slightly from that used by the SRA; with recruits considered to be those individuals that were less than the species known average length at sexual maturity. The recruitment lengths used for both large and small bodied species were derived from published scientific literature and where that was not available, by inferring the cut-offs from closely related ‘surrogate’ species. The three metrics were aggregated using the Recruitment Indicator Expert Rule set (Carter 2012).

As dictated by the methodology, computation of the Expectedness metric OP and the three Recruitment metrics was at the valley – altitude band scale rather than at the individual site scale. As this project required data attributed at the stream segment scale, all sites within each valley altitude band were assigned the same OP and recruitment metric scores but retained their unique OE and three nativeness metric values.

All three indicators were then combined using the Fish Index Expert Rule set (Carter 2012) to calculate an overall Fish Condition Index (SRA ndxFS). The Fish Index Expert Rules analysis is weighted as SR-FIe > SR-FIr > SR-FIn.

Biotic measures of ecosystem condition have often included single indicators based on species diversity, dominance or presence/absence. The indices (as described above) for this project have been developed to capture information from individual, population and community levels to provide a more integrated assessment of biological integrity (Roper et al, 2011, Harrison and Whitfield 2006, 2004).

The output generated by the Expert Rules analysis is scaled between the minimum and maximum indices of 0 to a maximum value of 87.63. Higher values representing 'healthier' fish communities. Following an examination the data distribution for NSW freshwater fish assemblages five scoring classes were adopted for this project: very good (70–87), good (52–70), fair (35–52), poor (17–35) and very poor (0–17) which approximated a normal data distribution.

These classes can be used to provide information and or guidance to support planning and management decisions such as establishing goals to protect or restore biological integrity, prioritise NRM funding and or research programmes and provides a consistent and repeatable framework for determining progress towards stated goals in aquatic biodiversity protection and restoration (Harrison and Whitfield 2004).

2.3.2 Generalised Additive Model analysis

The fish community status data was joined to the master Geofabric environmental attributes/River Style® classifications geodatabase table using the segment number identifier to create a samples-with-data table for analysis. Given that all fish community status data utilised were collected from NSW waterways, we utilised River Style® planform and River Style® substratum categories as the geomorphological/river typology classification.

Generalised Additive Modelling (GAM) analysis (Hastie and Tibshirani 1990) was used to model relationships between three of the fish assemblage metrics/indicators/index OE (the site-based Expectedness metric); Fish Nativeness (the site-based indicator derived from the three nativeness metrics), and ndxFS (the site/zone-based index derived from the Expectedness, Nativeness and Recruitment indicators). The relationships were modelled with continuous and categorical environmental attributes of stream segments to allow fitting of complex non-linear relationships based on nonparametric regression and smoothing techniques.

Advantages of this approach are that it allows the predictor variables to be from a range of different relationships with the response, and is robust to correlations amongst predictor variables. However, GAM is computationally demanding and a model fitting procedure utilising all 18 continuous and two categorical environmental variables was not possible on a standard computer. It was necessary to first determine which subset of predictor variables was best suited to each response. To look for parsimony, we fitted up to six subsets of four to eight predictor variables to each model, with each predictor being able to choose up to four spline (smoothing) parameters. At each step we asked SAS proc GAM (SAS institute 2012) to run a forward stepwise selection strategy and choose the best predictors in order of importance to the prediction as determined by the reduction in Akaike's Information Criteria (AIC). After subsets had been run, we chose the eight environmental variables that were clearly the best for each fish assemblage response variable and then re-ran the forward selection strategy on those 8 variables. We then looked at a scree plot of the AIC values associated with the final selection strategy and chose the model where the decrease in the AIC value was negligible.

The selected model for each response variable was then used to predict the values for each response variable for each Geofabric stream segment within NSW based on its respective set of priority environmental attributes.

The projection layer contained 162,438 individual stream segments across NSW. The five scoring classes of: very good (70–87), good (52–70), fair (35–52), poor (17–35) and very poor (0–17), were then assigned to the relevant stream segment (see Appendix A).

2.4 Threatened species distributions

All available records (see 2.2.2) for each species were tabulated with each record requiring a minimum of species identification, date of collection, spatial coordinates, datum, locality description and data source. Disparate coordinate formats were all projected to a common datum (GDA94) in ArcGIS.

For Freshwater (Eel-tailed) Catfish, Olive Perchlet, River Blackfish, Southern Purple-spotted Gudgeon, and Southern Pygmy Perch, only a subset of available species records were assigned a SEGMENTNO and utilised for subsequent modelling, given the discrete locations of these threatened species. For Fresh water (Eel-tailed) Catfish, Olive Perchlet, and Southern Pygmy Perch, only records from within the Murray-Darling Basin were used, as these are the populations relevant to the species threatened status in NSW. Only records of River Blackfish collected from the south-east coastal river systems between the La Trobe and East Gippsland catchments were used to model the distribution of the endangered River Blackfish population of the Snowy River, given that Hammer *et al.* (2014) identified Blackfish within this range as a discrete candidate taxon distinct from other River Blackfish populations. Similarly, only records of *Mogurnda adspersa* south of the Burdekin River were utilised to model the distribution of Southern Purple-spotted Gudgeon in coastal drainages, given that Adams *et al.* (2013) found that populations in northern Queensland represent a separate undescribed taxon.

Any records considered to be translocated populations (including recorded translocations and genetic analyses) occurring outside of their natural distribution were not utilised for modelling.

As the intent of this project was to model the likely current, not historical probability of encountering each species in any particular un-sampled stream segment, we only utilised sampling records collected on or after 1 January 1994.

Predicting the geographic distribution of each of the listed freshwater threatened fish species was done via maximum entropy modelling using MAXENT software (Phillips et al, 2006). The principle of maximum entropy states that, subject to precisely stated prior data, the probability distribution which best represents the current state of knowledge is the one with largest entropy (Jaynes, 1963).

MaxEnt 3.3.3 is a widely used species distribution modelling program that utilises presence records to generate probabilities of occurrence based on a suite of environmental variables quantified across an area of interest. MaxEnt has been demonstrated to perform well when compared to a range of alternative traditional and machine-learning modelling approaches (Elith *et al.* 2006, Phillips *et al.* 2006, Radosavlijevic and Anderson 2014). MaxEnt uses a machine-learning algorithm following the principle of maximum entropy to compute the likelihood of the species in question occurring at any point in the area based on environmental conditions observed at known species locations and contrasted by random background segments within the area being modelled (Phillips and Dudík 2008).

The samples-with-data approach demonstrated by Elith *et al.* (2011) was used for the current modelling exercise. Each species record utilised the same suite of environmental variables and for all species we used 10-fold cross validation to estimate uncertainty around the individual variable response curves, the overall model performance, the model predictions and other statistics that MaxEnt generates.

Selection of geomorphological/river typological classification had a major influence on dictating the number of available species and background data points, so three models were initially run using the default MaxEnt settings to determine which classification scheme was most appropriate for each taxon. All three models used the full suite of 18 continuous variables, but each used a different categorical river type classification system:

1. the Geofabric network AHGFFType (See section 2.5);
2. the full set of 65 River Style® categories (omitted all segments with null value RiverStyle® categories of 1, 10 and 37); and
3. differentiated River Styles® Planform and Substratum classes (omitted all segments with null value RiverStyle® categories of 1, 10 and 37 and all reaches where River Styles® planform and/or substratum had not been characterised).

The model that resulted in the greatest mean area under the receiver operating characteristic curve (AUC) (Phillips, 2006) with the smallest standard error bars was selected for further tuning on a species by species basis.

Each species model was tuned by incrementally increasing the regularisation parameter (β) in 0.5 increments until the mean test omission rate and its error bars approximated the predicted omission rate. The lowest value of β that maximised the AUC and did not show evidence of over-fitting was accepted as the final model. All but one 'best' species model resulted in AUC scores exceeding 0.75, the threshold value considered indicative that the model provides defendable predictions (Elith, 2002). Figure 2 shows an example of both the test omission rate and predicted area as a function of the cumulative threshold, averaged over the replicate runs, and the receiver operating characteristic (ROC) curve for the same data, again averaged over the replicate runs.

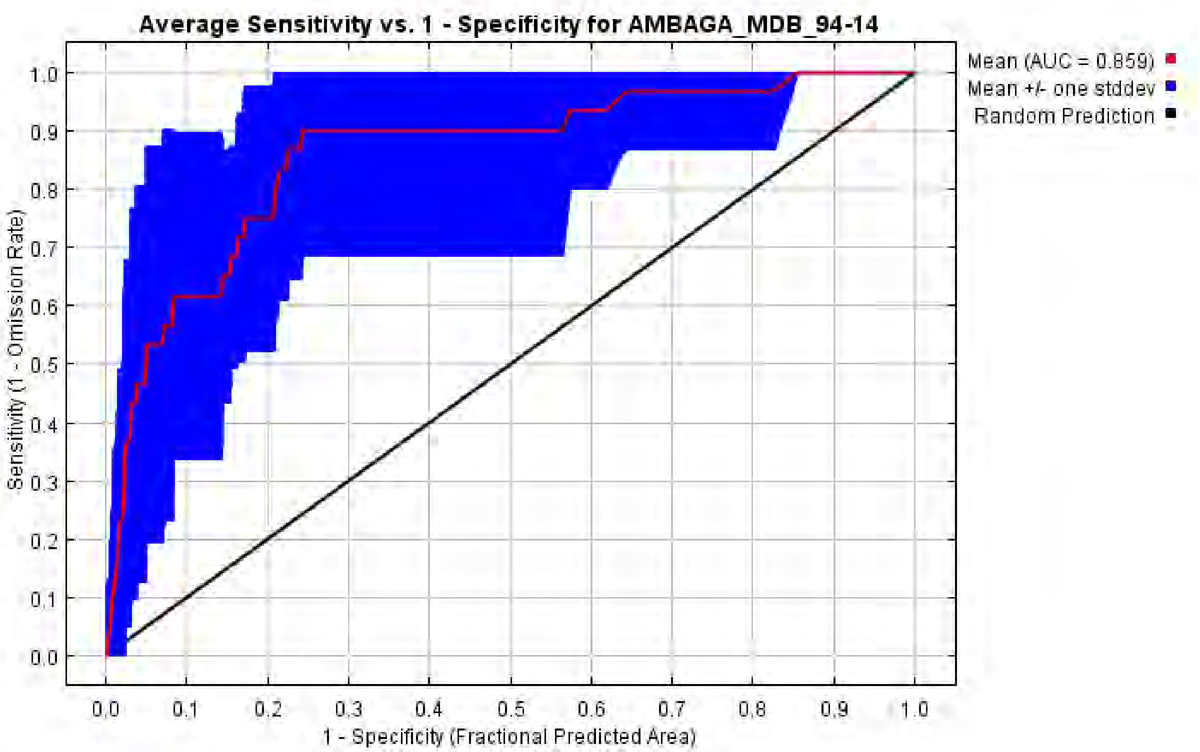

Figure 2 - Examples of the test omission rate and predicted area curve and the receiver operating characteristic (ROC) curve for Western population of Olive Perchlet - ***Ambassis agassizii***

Background environmental data sample selection bias was managed by using target group backgrounds representing all sampled locations within the background distribution when >1,500 sampled target group background locations where available. For species with < 1,500 target group background segments available, a random sample of 10,000 background segments specific to the catchments representing the natural distribution of each species was used, with the probability of selection weighed by the length of each stream segment. However, there were instances where the number of available target group background stream segments within the expected natural distribution of a species or populations was < 10,000, in which case all available stream segments where utilised.

MaxEnt produced high quality useful models for 16 of the 20 species analysed. The three sub-optimal models include two where the average, but not the lower 95% confidence intervals exceed the acceptable 0.75 threshold and only a single species where no acceptable model could be produced.

2.4.1 Assigning records to stream segments within the Australian Hydrological Geospatial Fabric

By assigning other attributes to the Geofabric framework the project was able to introduce key environmental attributes associated with a particular segment or catchment, including geomorphic information (River Style®), and other abiotic attributes.

Species records where plotted in ArcGIS over the Geofabric background layer. Every threatened species collection location was individually scrutinised based on both its position and locality description, and manually assigned to the nearest appropriate Geofabric stream segment by assigning the record to the SEGMENTNO field of the Geofabric geodatabase. In instances where the coordinate position and locality description were inconsistent, the locality description was given precedence in assigning the record to a stream segment. If the coordinate position was suspect and no locality description was available, that record was omitted from further analyses. In several instances, existing wetland habitats where threatened fauna had been collected were not registered as a stream segment with the Geofabric surface hydrology network. In these cases, the record was assigned the nearest available wetland stream segments SEGMENTNO as a surrogate.

2.5 Environmental attributes

A total of 910 environmental attribute variables are available from Stein et al. (2012) which can be linked to individual stream segments in the Geofabric background layer using the shared SEGMENTNO field. The project team screened this list of variables and selected an initial suite of 29 continuous and 2 categorical variables representing potential drivers of freshwater fish distribution (Appendix C). Each variable was plotted in ArcGIS to ensure that the data incorporated adequate spatial resolution across NSW (i.e. the variable exhibited spatial variation across the state and that the variability was not so localised that the environmental attribute had little scope for modelling broadscale processes). Secondly, variables were visually scrutinised for completeness/accuracy by the project team.

Of the 31 variables, five stream reach scale land-use attributes STRPOPMEAN (the mean human population size within the stream segment), STR_PEST (the mean area of land subject to pesticide use within the stream segment), STR_FERT(the mean area of land subject to fertilizer use within the stream segment , SUB_PEST (the mean area of land subject to pesticide use within the subcatchment upstream of the stream segment), SUB_FERT (the mean area of land subject to fertiliser use within the subcatchment upstream of the stream segment)) were too spatially localised to be useful for modelling broad-scale processes and were adequately represented by the catchment scale attribute for the same parameter. Three connectivity variables (BARRIERDOWN, CLIFFDOWN, WFALLDOWN (binary variables indicating the presence/absence of and artificial barrier, cliff or waterfall within the flow path downstream of the segment) were considered too incomplete to be useful and one terrain variable (the distance downstream to the waterways outlet to the sea) was only useful in the context of a small number of the species being modelled. These nine variables were not utilised further.

A pair-wise Pearson correlation matrix was generated for the remaining 18 continuous variables using a dataset of 3,080 sampled reaches derived from the NSW Fisheries Freshwater Fish Research Database (DPI, 2013). This analysis indicated that eight of the 18 variables were at least moderately correlated ($r > 0.5$) with at least one other variable. All but one of the correlations was amongst runoff variables. Of these: RUNANNMEAN (annual mean runoff), RUNPCTL5 (5^{th} percentile runoff) and RUNPCTL95 (95^{th} percentile runoff) could be omitted without sacrificing substantial interpretability. The remaining correlated variables: RUNMTHCOFV (coefficient of variability of runoff amongst months of a year) and RUNANNCOFV (coefficient of variability of total annual runoff amongst years); RUNJAN (average runoff in January (mid-Summer)), RUNAPR (average runoff in April (mid-Autumn)), RUNJUL (average runoff in July (mid-Winter)) and RUNOCT (average runoff in October (mid-Spring); and STRCOLDMTH (the average temperature of the stream in the coldest month) and STRELEVMEAN (the altitude of the stream segment) were retained given their relevance to interpretation of the outputs of the models in the context of environmental flow programs and river regulation in Australia.

Whilst this makes response curves for each of these variables harder to interpret, it does not compromise the modelling process. The two categorical attributes (BASINNO (identifier of the topographically defined basin within which the segment occurs), AWRCNO (the Australian Water Resources Commission identifier for the basin within which the segment occurs)) were also omitted as although they were found to improve the performance of the models substantially during trial runs, they limited the processes ability to model the potential distribution of species in basins and drainages that have never been or are poorly sampled. Therefore, we considered a post-hoc assessment of the predicted distribution outside of each species known range on a case-by-case basis as a more robust approach.

Two sources of readily available geomorphological/river typological classifications were also utilised. The attribute field AHGFFType within Geofabric geodatabase provides a broad categorisation of segments into lotic segments (NetworkFlowSegment), lentic segments (NetworkWaterAreaSegment) and ‘others’ (NetworkArtificialFlowSegment). Whilst overly simplistic, it effectively distinguished riverine from wetland habitat types with entire national coverage.

River Styles® (Brierly and Fryirs 2005) represents a much higher resolution categorical classification than AHGFFType . River Styles® is based on a set of procedures for classifying river character within a nested hierarchy of criteria based on valley setting, channel planform, geomorphic units, and bed material. DPI Water has compiled a spatial dataset of River Styles® classifications for a large number of the waterways of NSW: RiverStyles.gdb (Brierley et al. 2011, Healey et al. 2012). Although River Styles® offers a higher resolution classification suitable for modelling species with a sufficient density of spatial records within NSW, it can’t be used when a majority of the presence records are inter-state.

The current project accessed a 2012 version of RiverStyles.gdb from DPI Water and utilised the field labelled ‘RIVER_STYLE_CODE_AND_DESC’, consisting of 65 River Style® categories. From the descriptor for each category we also generated two new fields representing Planform

(34 categories) and Substratum (8 categories) for each stream segment. River Style®, planform and substratum categories were then assigned to each attribute field of the corresponding Geofabric segment.

The resulting GIS layer provided a database representing every stream segment in south-eastern Australia (as provided by the Geofabric) and its environmental attributes for 18 continuous environmental attribute variables and four categorical variables representing geomorphological classification (one available across the entirety of south-east Australia and three only available for a majority on NSW waterways).

This Geofabric environmental attributes/River Style® classifications geodatabase table was used to create species-with-data 'Samples' tables of presence records, 'Environmental layers' tables (environmental background sites), and an output 'Projection layers' table for input in MaxEnt (see Appendix D)

2.6 Production of threatened species distribution maps

We utilised logistic output to plot the predicted distribution of each species. This output equates to a probability that the species will be observed in each stream segment, given the environmental conditions that exist there relative to the environmental conditions where the species is known to occur, and is represented with a value ranging from 0 to 1. (Phillips & Dudík 2008, Law, et al. 2015).

The projection layer contained 162,438 individual stream segments across NSW. However, due to choice in river type classification and missing data for four of the Geofabric environmental attribute fields (RUNMTHCOFV, RUNANNCOFV, RUNPERENIALITY (runoff pereniality) and CATPOPMEAN (mean human population density of the catchment upstream of the segment)), it was only possible to project to 154,512 reaches when using the Geofabric AHGFFType classification (95.12% of stream segments), 78,551 reaches when using the raw River Styles® classification (48.36% of stream segments) and 78,174 reaches when using River Syles® planform and substratum classifications (48.12% of stream segments). Fortunately, many of the un-projected segments represented small order streams providing limited fish habitat, and as such was not considered a significant loss in the final projection layer.

In order to produce distribution maps representing stream segments where each species is known, likely to, or could potentially occur, we considered both the conservative 'lowest presence threshold' (LPT) approach (Growns et al. 2013; interpreted as identifying stream segments predicted as being at least as suitable as those where a species' presence has been recorded), and a slightly less conservative approach of defining the minimum logistic probability of occurrence value as the 5th percentile of the available presence records (similar to Peason et al 2007; Kumar and Stohlgren 2009; Qld DISTI, 2015; this approach accounts for instances where the occasional recording of the presence of a species is within sub optimal habitats or data represents outliers in the data set).

Distribution maps were initially produced based on the 5th percentile approach; however expert rules were used to further refine the data, recognising the importance of connectivity segments between reaches and eliminating the 'noise' of scattered and isolated segments. These outputs were classified using a similar approach by Law et al. (2015) and divided into three evenly distributed classes representing different levels of probability: 0-0.33 = Low Probability; 0.33-0.66 = Medium Probability; 0.66-1 = High Probability. While initial distribution maps included all probabilities, the outputs did not provide for a useful depiction of critical river reaches for threatened species conservation and management. Given the noise (scattered representation of probabilities) generated for occurrences probabilities below 0.33, and recognising inherent limitations on attribute data, it was determined that a more conservative approach be taken for the final indicative distributions.

In keeping with the SRA and MER programs (Mushal et al. 2010), waterways significant for fish had to have an averaged daily flow greater than 5 megalitres/day. These waterways were identified using the environmental attribute RUNANNMEAN divided by 365 (Stein et al. 2012). Following the expert review of outputs it was determined that for five (5) of the small bodied species the inclusion of streams with flows less than five megalitres/day was warranted to better reflect habitat suitable for those specific species.

To produce the final indicative distribution maps the Low class (0-0.33) was conservatively eliminated and the Medium and High classes were merged. This approach ensures a high level of confidence in the final indicative distribution layers. The predicted values for each river reach were then converted from the Geofabric framework to the higher resolution 2013 NSW Strahler Stream Order Hydroline.

Table 2 lists the freshwater threatened species and population distributions that have been revised as a result of this project (see Appendix B). It is important to remember that there is always a possibility that each species may be found outside the bounds of the indicative distributions displayed.

Table 2 Freshwater threatened species distributions revised by this project

Critically endangered species	Fitzroy Falls Spiny Crayfish - *Euastacus dharawalus*
	Flathead Galaxias - *Galaxias rostratus*
Endangered species	Australian Grayling - *Prototrocetes marena*
	Eastern Freshwater Cod - *Maccullochella ikei*
	Macquarie Perch - *Macquaria australasica*
	Purple Spotted Gudgeon - *Mogurnda adspersa*
	Southern Pygmy Perch - *Nannoperca australis*
	Trout Cod - *Maccullochella macquariensis*
	Australian Grayling - *Prototrocetes marena*
Vulnerable species	Murray Crayfish - *Euastacus armatus*
	Silver Perch - *Bidyanus bidyanus*
Endangered populations	Darling River Hardyhead population in the Hunter River catchment - *Craterocephalus amniculus*
	Murray-Darling Basin population of Eel Tailed Catfish - *Tandanus tandanus*
	Snowy River population of River Blackfish - *Gadopsis marmoratus*
	Western population of Olive Perchlet - *Ambassis agassizii*

Table 3 lists threatened species that did not receive distribution modelling as part of this project given the limited number of records, the limited number of correlated environmental attributes and/or limitations of the modelling in providing confidence in output. The distributions of these species remain as provided on the DPI web site: www.dpi.nsw.gov.au/fisheries/species-protection

Table 3 Freshwater threatened species distributions not revised by this project

Critically endangered species	Murray Hardyhead - *Craterocephalus fluviatilis*
Endangered species	Adams Emerald Dragonfly - *Archaeophya adamsi*
	Sydney Hawk Dragonfly - *Austrocordulia leonardi*
	River Snail - *Notopala sublineata*
	Oxleyan Pygmy Perch - *Nannoperca oxleyana*
Vulnerable species	Alpine Redspot Dragonfly - *Austropetalia tonyana*
	Buchanans Fairy Shrimp - *Branchinella buchananensis*

3 Discussion

One of the major limitations of natural resource management, particularly in relation to aquatic biodiversity, is the lack of state-wide fit-for-purpose data that supports a high level of confidence in evidence based decision making. To be fit-for-purpose data must be collected and applicable at an appropriate scale, consistent, repeatable and scientifically defendable. To address this, the FCTSD project was initiated and represents a fit-for-purpose dataset on the status of fish communities and threatened species distributions across NSW.

These data and corresponding spatial products may be used to inform land-use planning (e.g. strategic regional plans), natural resource management and planning (e.g. water resource management), and environmental impact assessment programs, at a scale suitable for state, regional and site planning. The spatial products should be used to guide regional planning endeavours by ensuring that aquatic biodiversity values are recognised, considered and conserved in their regional and state context. The revised threatened species distributions represent the last remaining areas of known and predicted presence of those species and are presented at a scale useful for regional- and site-based planning and assessment programs.

The focus of this project has been to provide fish community and threatened species information lacking at the state and regional planning contexts, however the spatial mapping products can also be used to inform, guide and focus conservation and/or rehabilitation actions across catchments at a river reach scale (see Case Study: Southern Pygmy Perch in the Lachlan River Catchment, section 4 of this report).

This project provides a strong evidence base for resource management decisions by presenting the status of fish communities across NSW, utilising the best available predictive models on species distributions and presenting this information spatially. This information may also improve the appreciation and understanding of fish communities and species distributions across catchments, regions and the state, by the broader community.

Decision makers strive to achieve a balance between resource use and the protection of the natural environment. In order to achieve that outcome, the delineation and spatial recognition of key environmental assets is paramount. While spatial identification of land-use and natural resource potential has been well documented, the identification of key aquatic assets is just as important to the NSW Government's objective to deliver a scientifically and evidence based decision making process. The development of the fish community status and threated species distributions has led to an improved capacity to report on overall fish status and threated species distributions at a variety of scales across NSW. The spatial products developed can inform natural resources planning at a variety of scales, for a variety of monitoring, reporting and planning requirements.

The project represents the first time that this type of innovative analysis has been undertaken across NSW and it is planned to be the first of a series of assessments/reports that will assist in tracking conservation and recovery efforts for aquatic (fish) biodiversity across NSW.

4 Case Study: Southern Pygmy Perch in the Lachlan River Catchment

The spatial mapping products generated by this project can be used to inform, guide and focus conservation and/or rehabilitation actions across catchments at a river reach scale. This is particularly the case for targeted threatened species recovery actions.

An example of this has already been implemented via the use of the threated species distribution models (MaxEnt) in the identification of potential refugia sites for Southern Pygmy Perch (*Nannoperca australis*) (SPP) in the Lachlan River catchment.

SPP are listed as an endangered species in NSW and DPI Fisheries surveys have confirmed that the introduced species Redfin Perch (*Perca fluviatilis*) has been steadily spreading upstream withinthe Lachlan River catchment since at least 2005. In areas where Redfin Perch are present the population of SPP has quickly declined or disappeared. Given the threat posed by Redfin Perch to a population of SPP in the Blakney Creek catchment, potential SPP locations were identified for further investigation as possible refuge sites for relocating SPP(see Figure 3). The river reach scale SPP distribution model provided valuable information on potential sites for focused on-ground assessment and included all three classes (low, medium, high) of SPP indicative distribution.

These targeted investigations resulted in refugia sites being identified and approved for population relocations while management strategies were developed to deal with the spread of Redfin Perch. While this work was possible using broad scale survey techniques and expert knowledge, significant efficiencies in time and resources were achievable utilising the information developed by the FCTSD project. Other possible sites have also been identified and will be the focus of future surveys and assessments of the distribution and recovery of SPP.

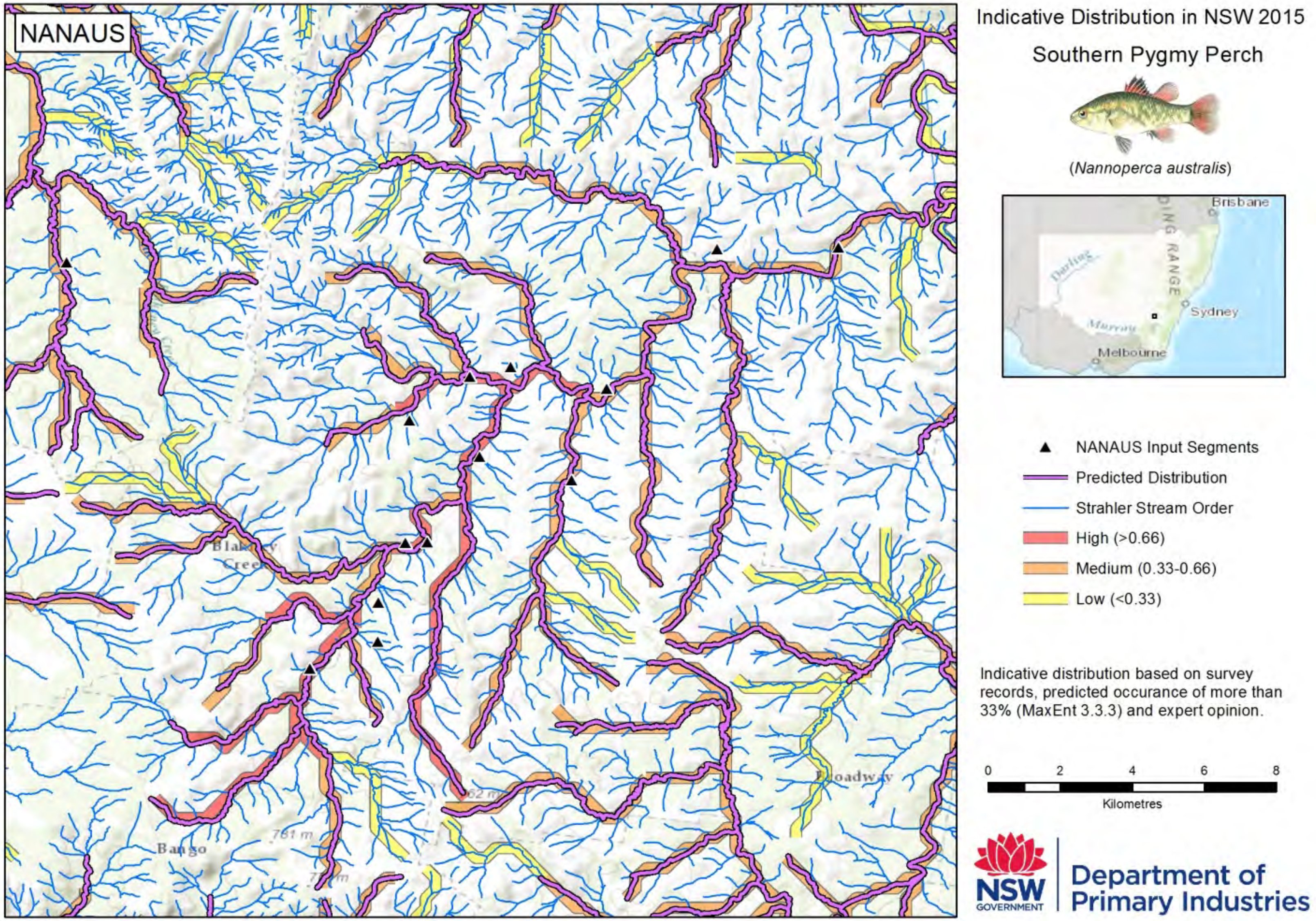

Figure 3 Indicative distribution of Southern Pygmy Perch *Nannoperca australis* used to investigate possible refuge sites.

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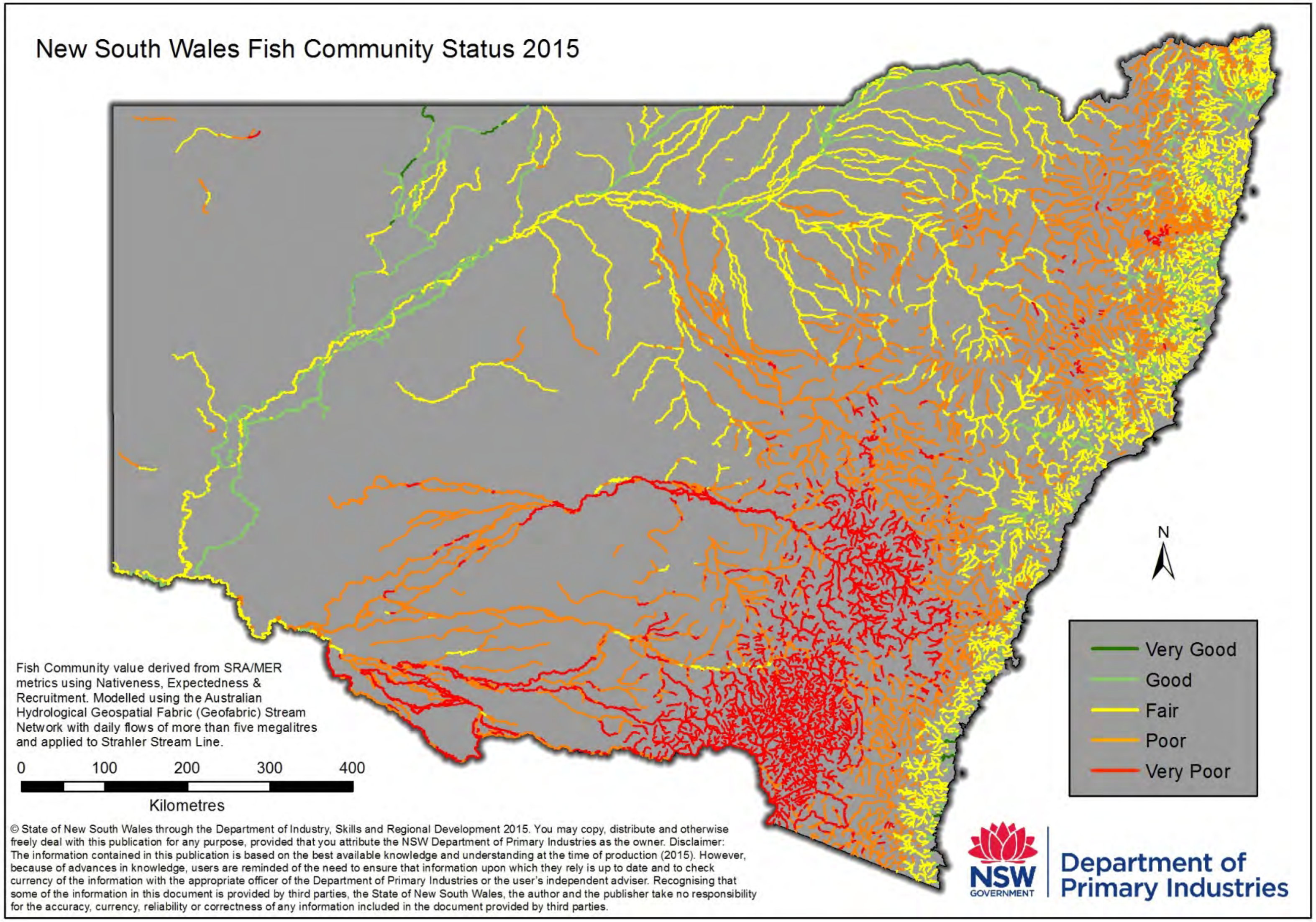
Appendix A – Fish Community Status of NSW

Figure 4 – Map showing the fish community status of NSW



Appendix B – Threatened Species Indicative Distributions

Figure 5 – Indicative distribution of the Australian Grayling *Prototroctes maraena*

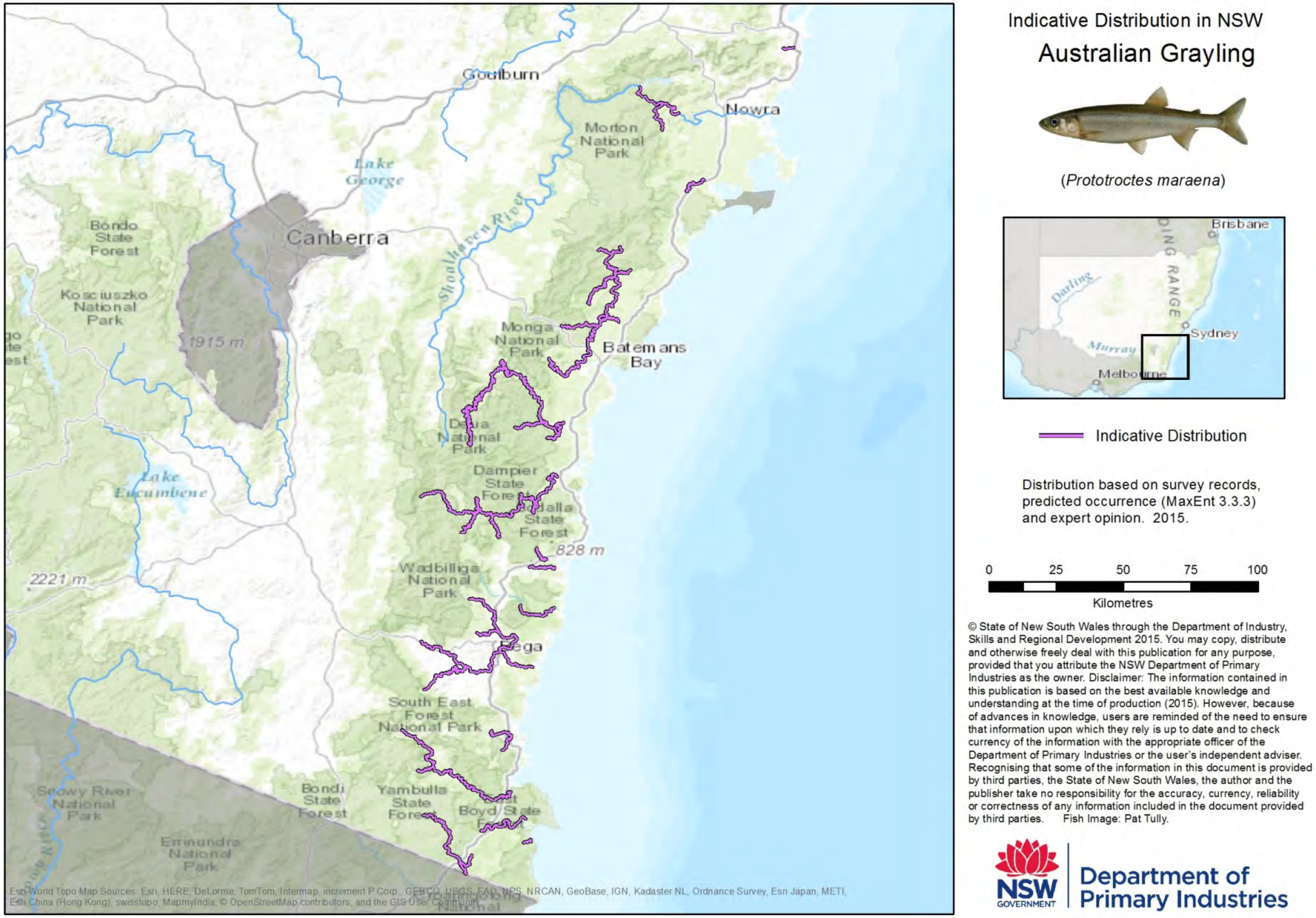


Figure 6 – Indicative distribution of the Darling River Hardyhead *Craterocephalus amniculus*

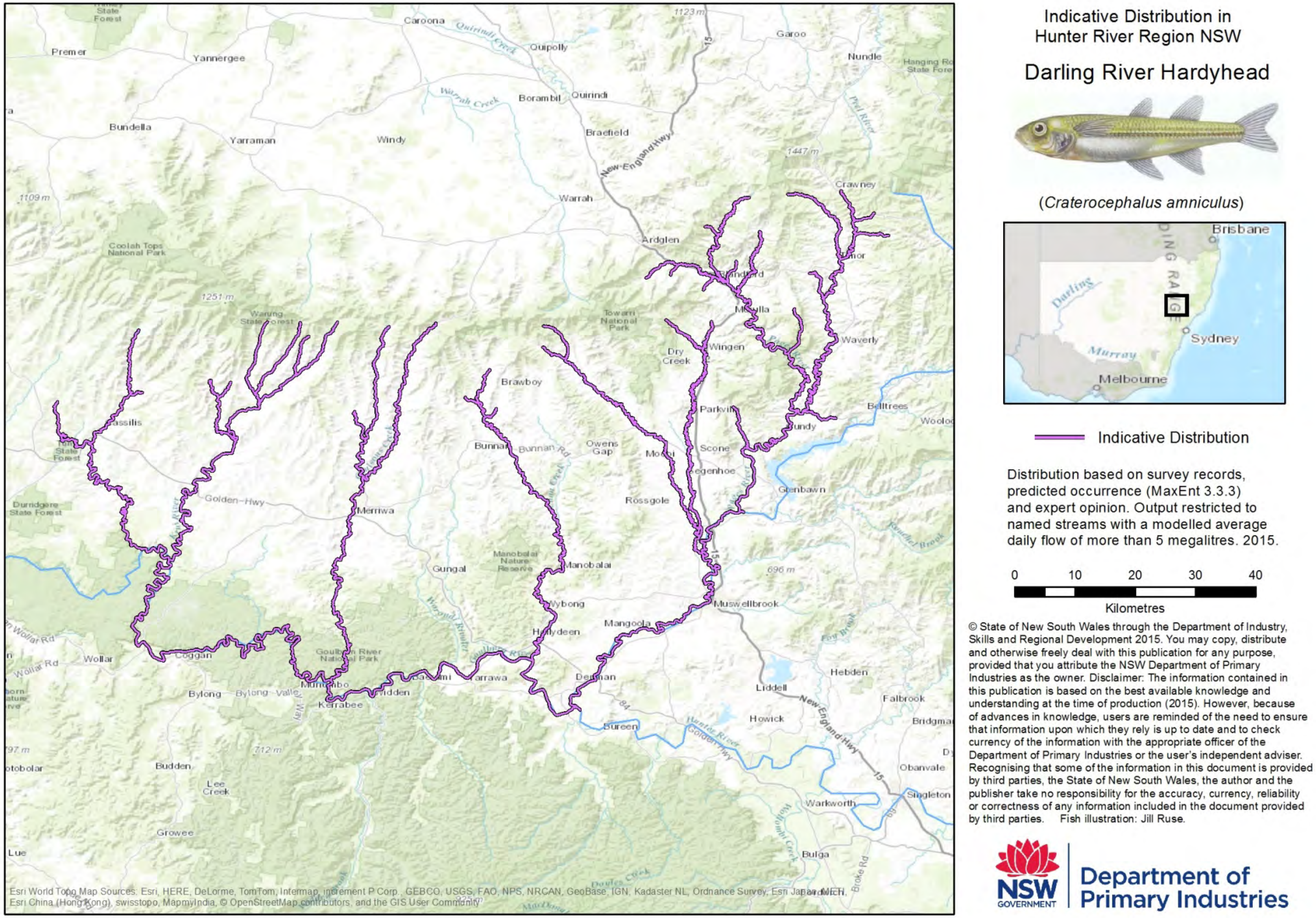


Figure 7 – Indicative distribution of the Eastern Freshwater Cod *Maccullochella ikei*

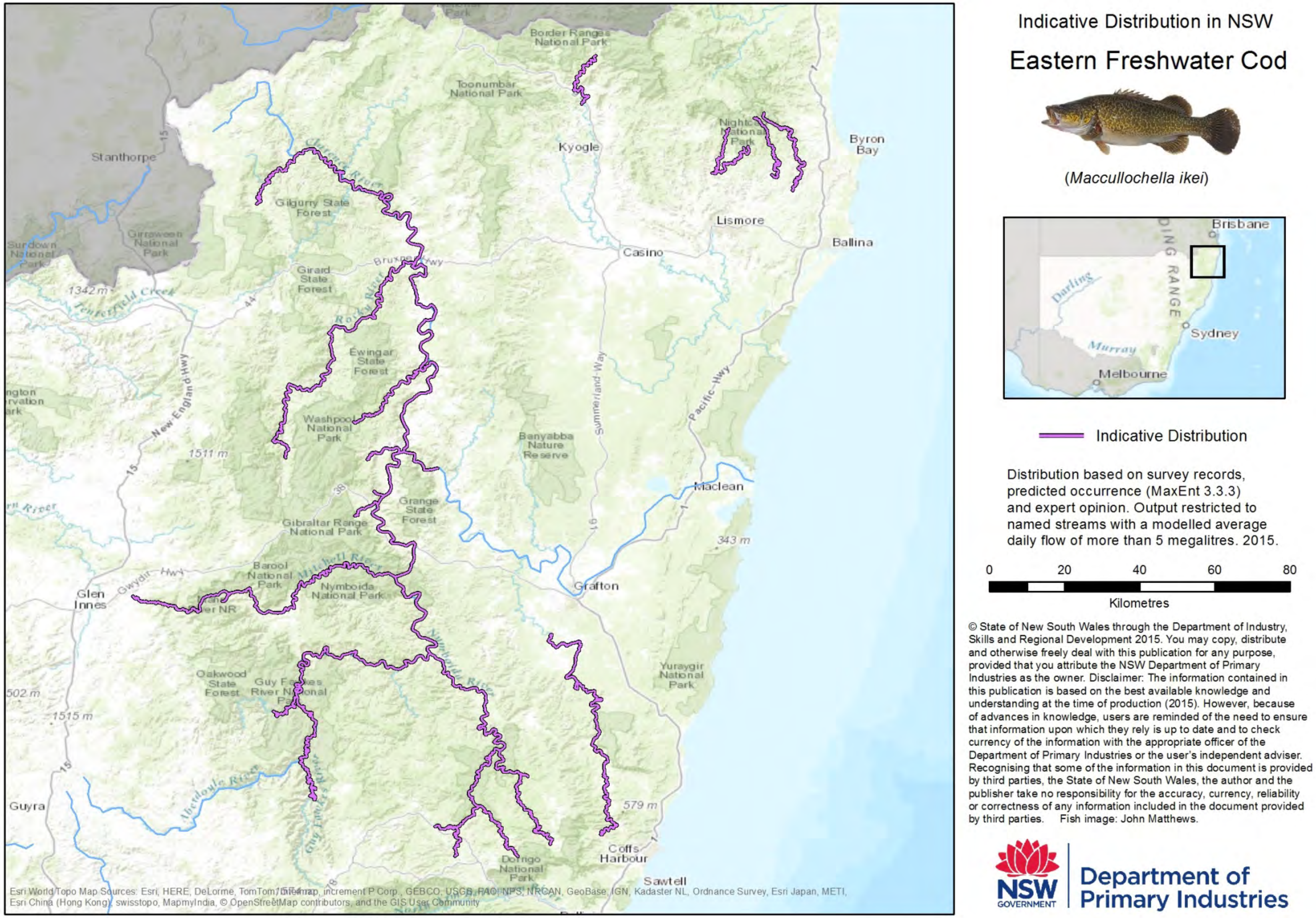


Figure 8 – Indicative distribution of the Eel Tailed Catfish *Tandanus tandanus*

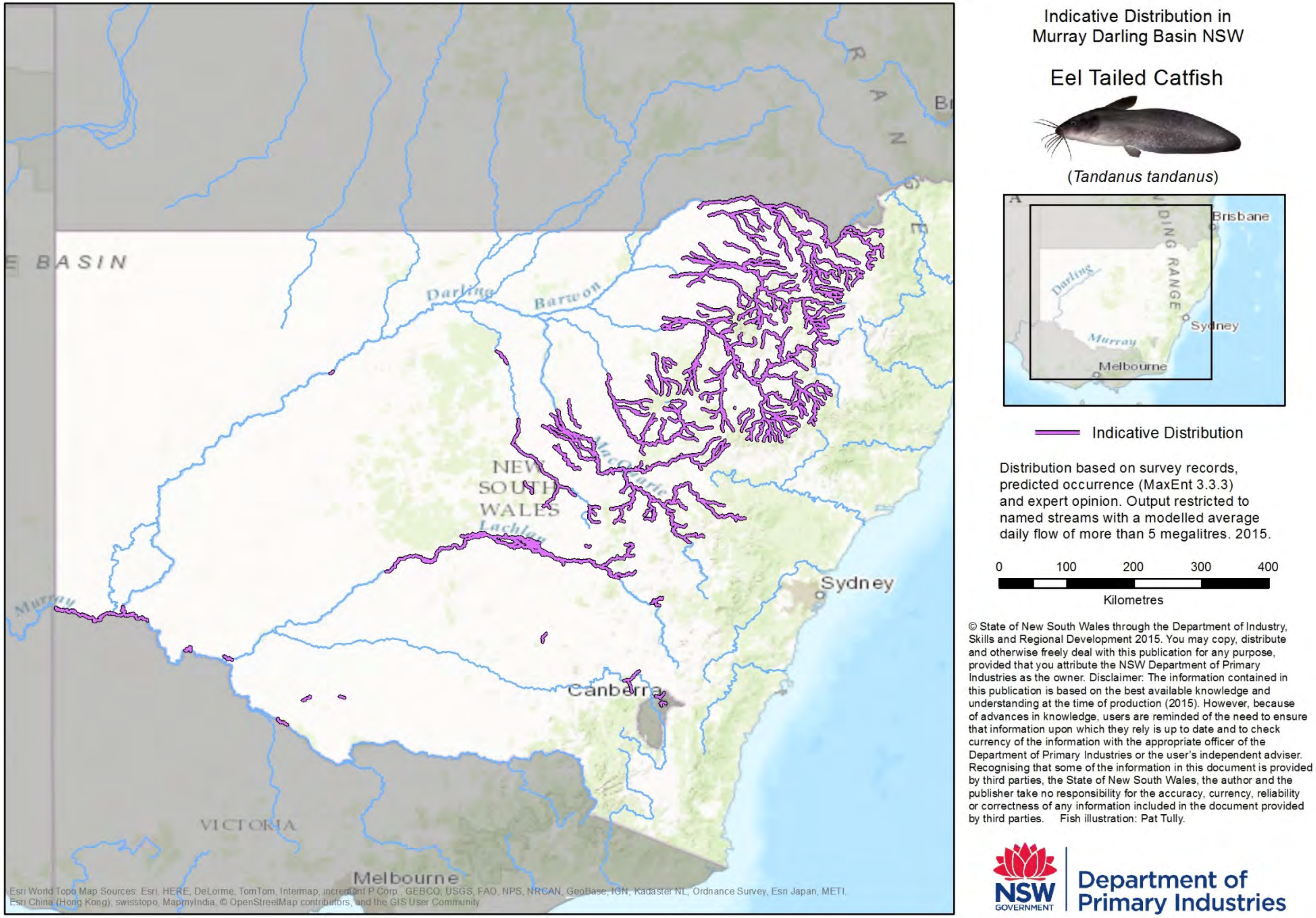


Figure 9 – Indicative distribution of the Fitzroy Falls Spiny Crayfish *Euastacus dharawalus*

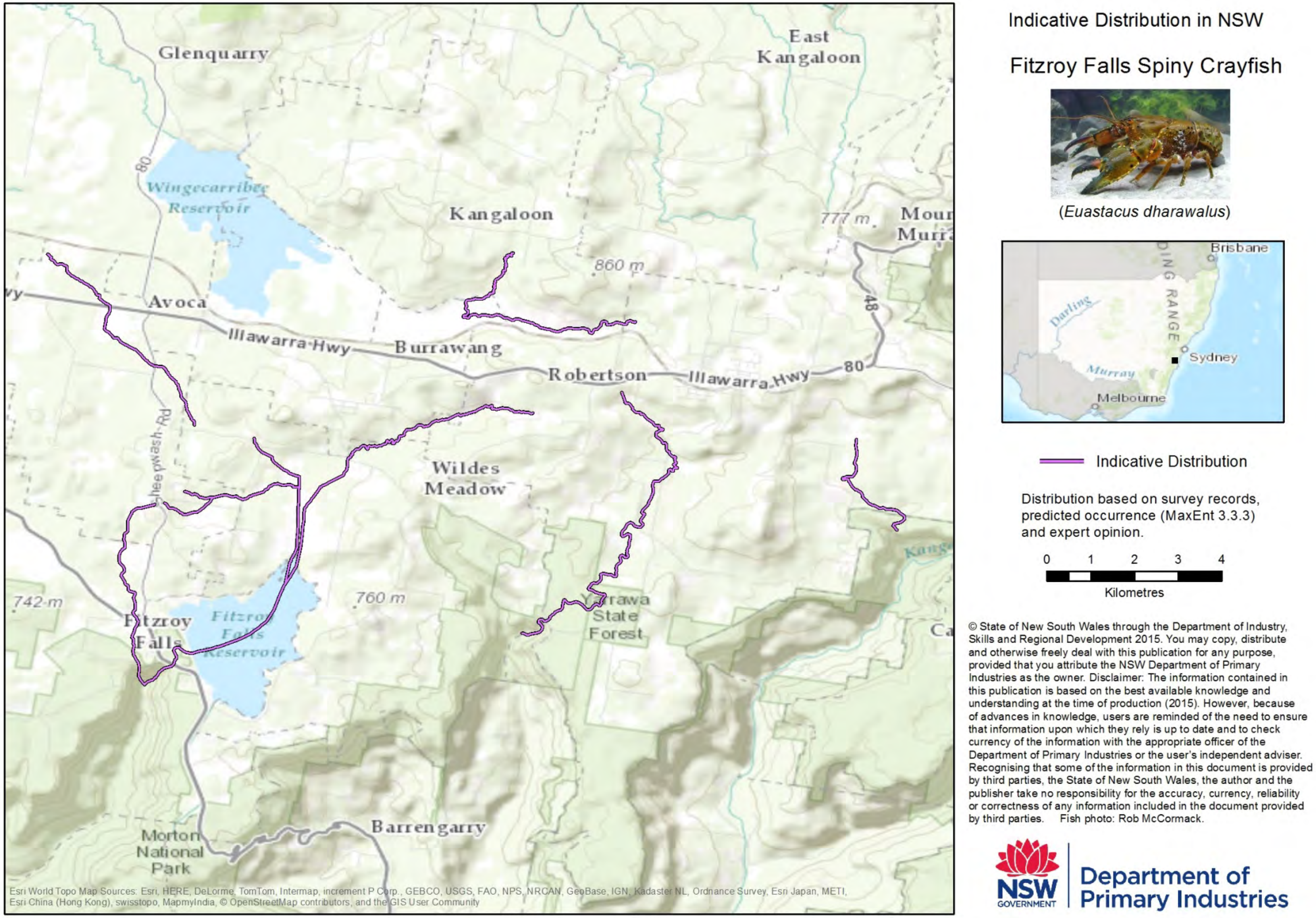


Figure 10 – Indicative distribution of the Flathead Galaxias *Galaxias rostratus*

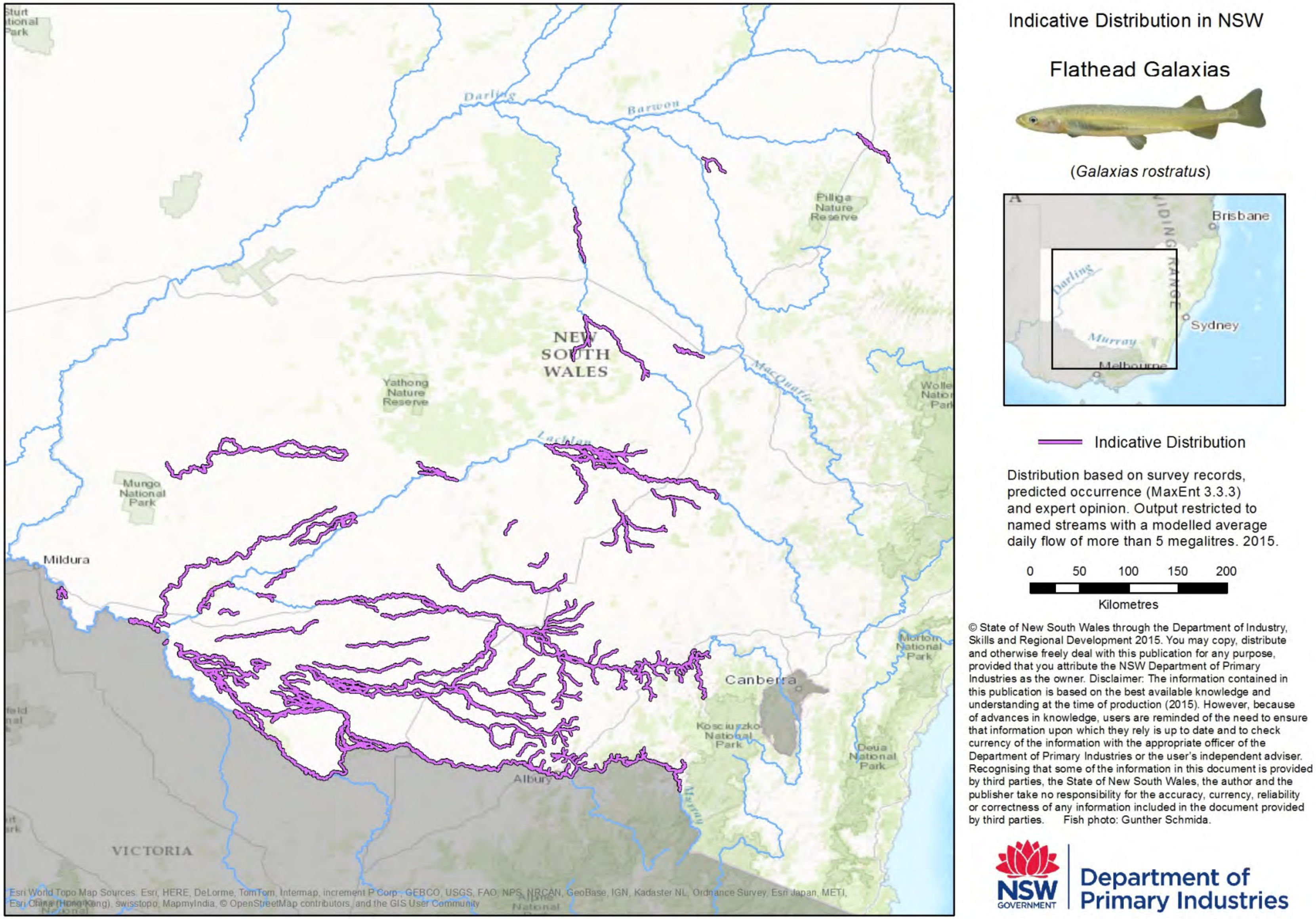


Figure 11 – Indicative distribution of the Macquarie Perch *Macquaria australasica*

Indicative Distribution in NSW

Macquarie Perch

(*Macquaria australasica*)

Indicative Distribution

Distribution based on survey records, predicted occurrence (MaxEnt 3.3.3) and expert opinion. Output restricted to named streams with a modelled average daily flow of more than 5 megalitres. 2015.

0 25 50 75 100
Kilometres

NSW GOVERNMENT Department of Primary Industries

Figure 12 – Indicative distribution of the Murray Crayfish *Euastacus armatus*

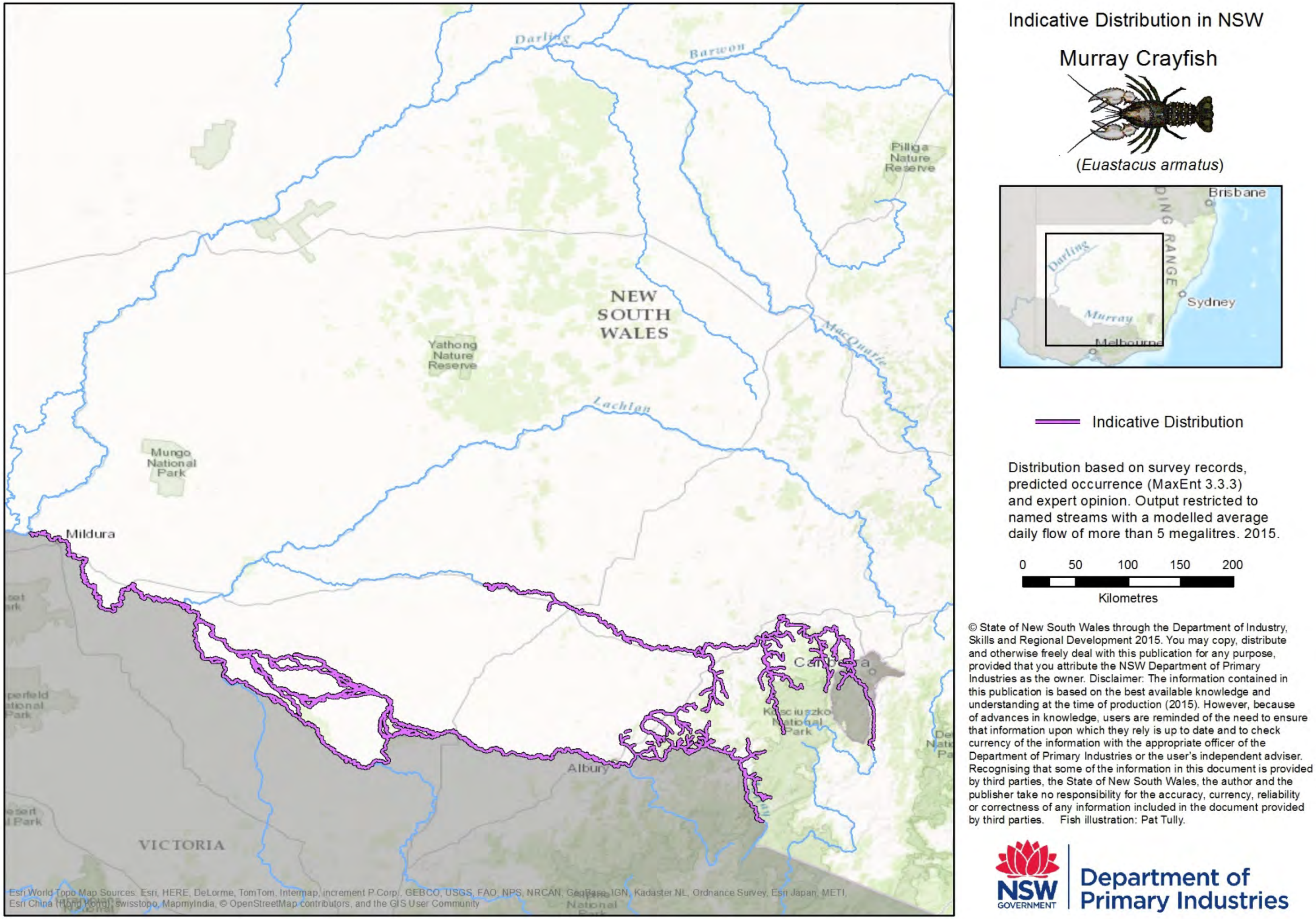


Figure 13 – Indicative distribution of the Olive Perchlet *Ambassis agassizii*

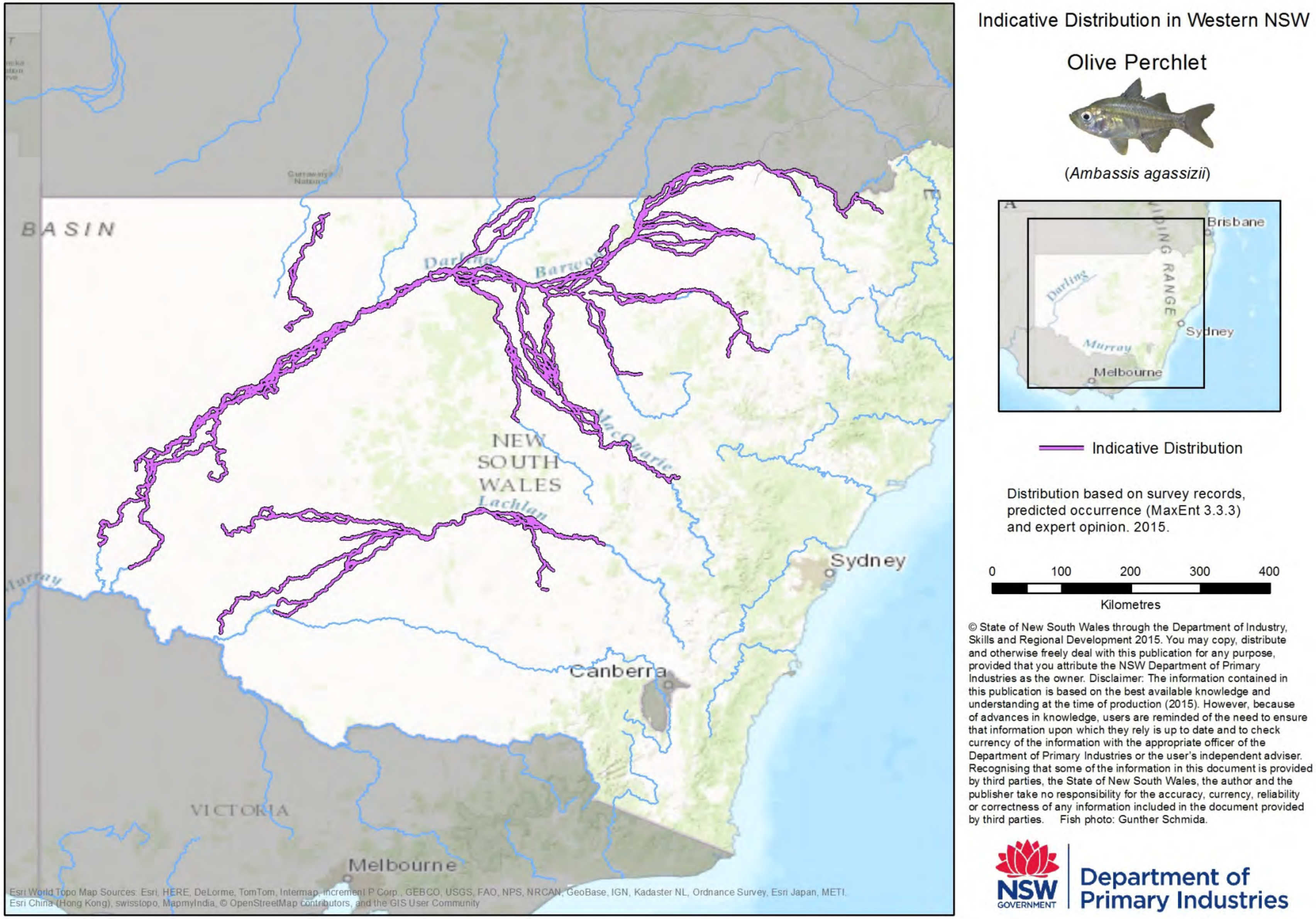
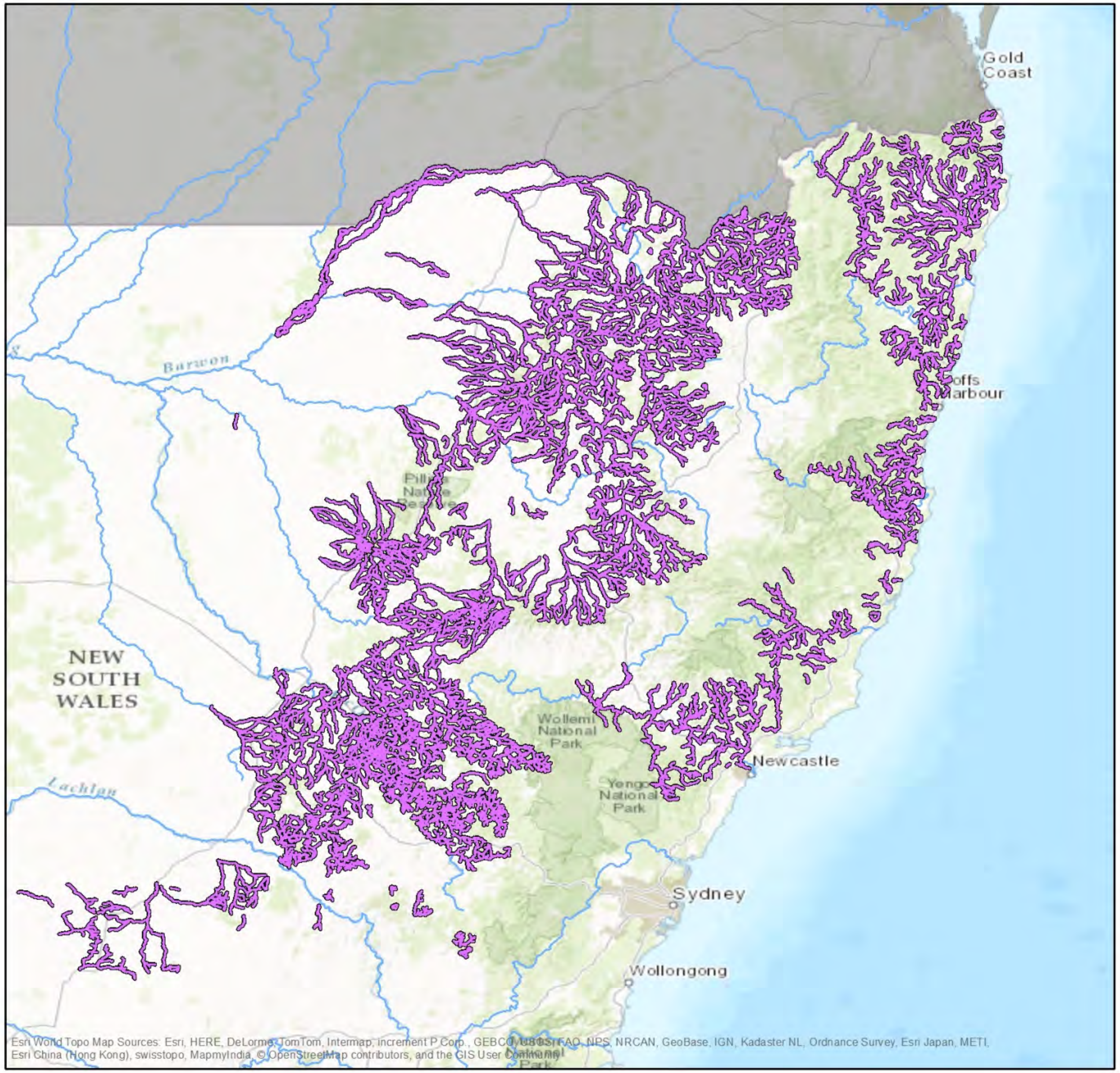


Figure 14 – Indicative distribution of the Purple Spotted Gudgeon *Mogurnda adspersa*



Indicative Distribution in NSW

Purple Spotted Gudgeon

(*Mogurnda adspersa*)

Indicative Distribution

Distribution based on survey records, predicted occurrence (MaxEnt 3.3.3) and expert opinion. 2015.

0 50 100 150 200
Kilometres

 Fish photo: Gunther Schmida.

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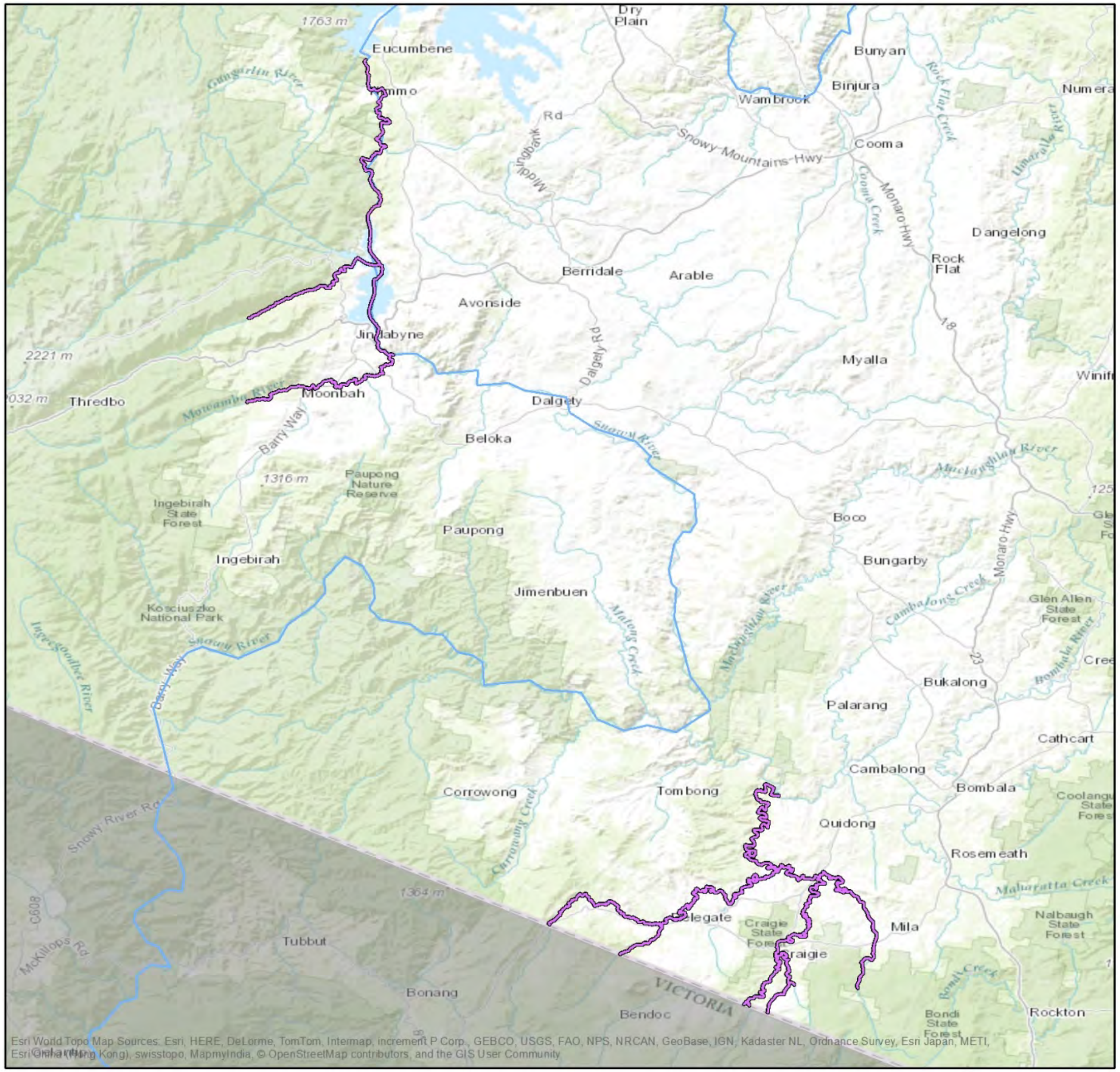
Figure 15 - Indicative distribution of the River Blackfish *Gadopsis marmoratus*



Indicative Distribution in Snowy River Region NSW

River Blackfish

(*Gadopsis marmoratus*)

Indicative Distribution

Distribution based on survey records, predicted occurrence (MaxEnt 3.3.3) and expert opinion. Output restricted to named streams with a modelled average daily flow of more than 5 megalitres. 2015.

0 10 20 30 40

Kilometres

 Fish photo: Gunther Schmida.

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Figure 16 - Indicative distribution of the Silver Perch *Bidyanus bidyanus*

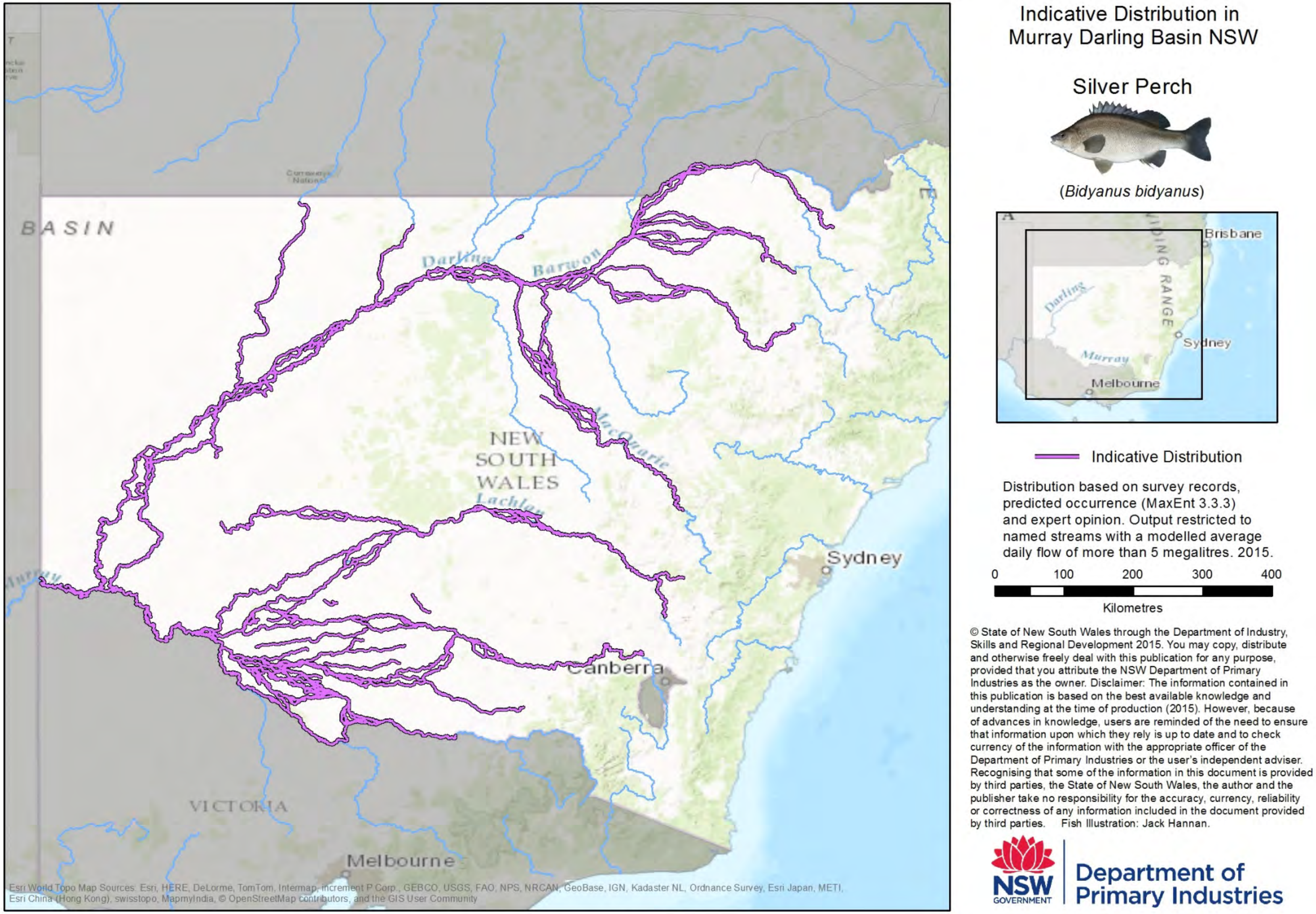


Figure 17 - Indicative distribution of the Southern Pygmy Perch *Nannoperca australis*

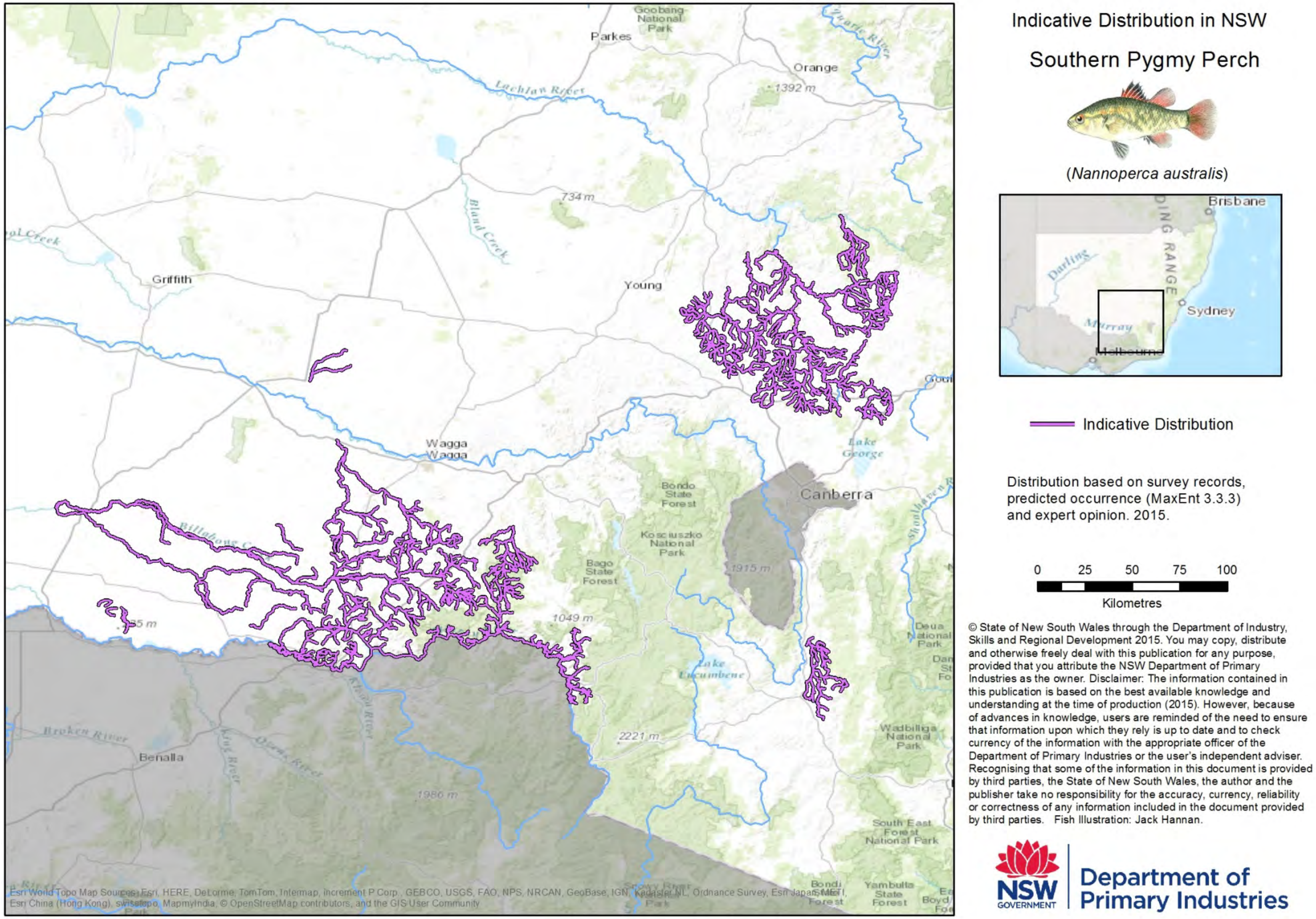
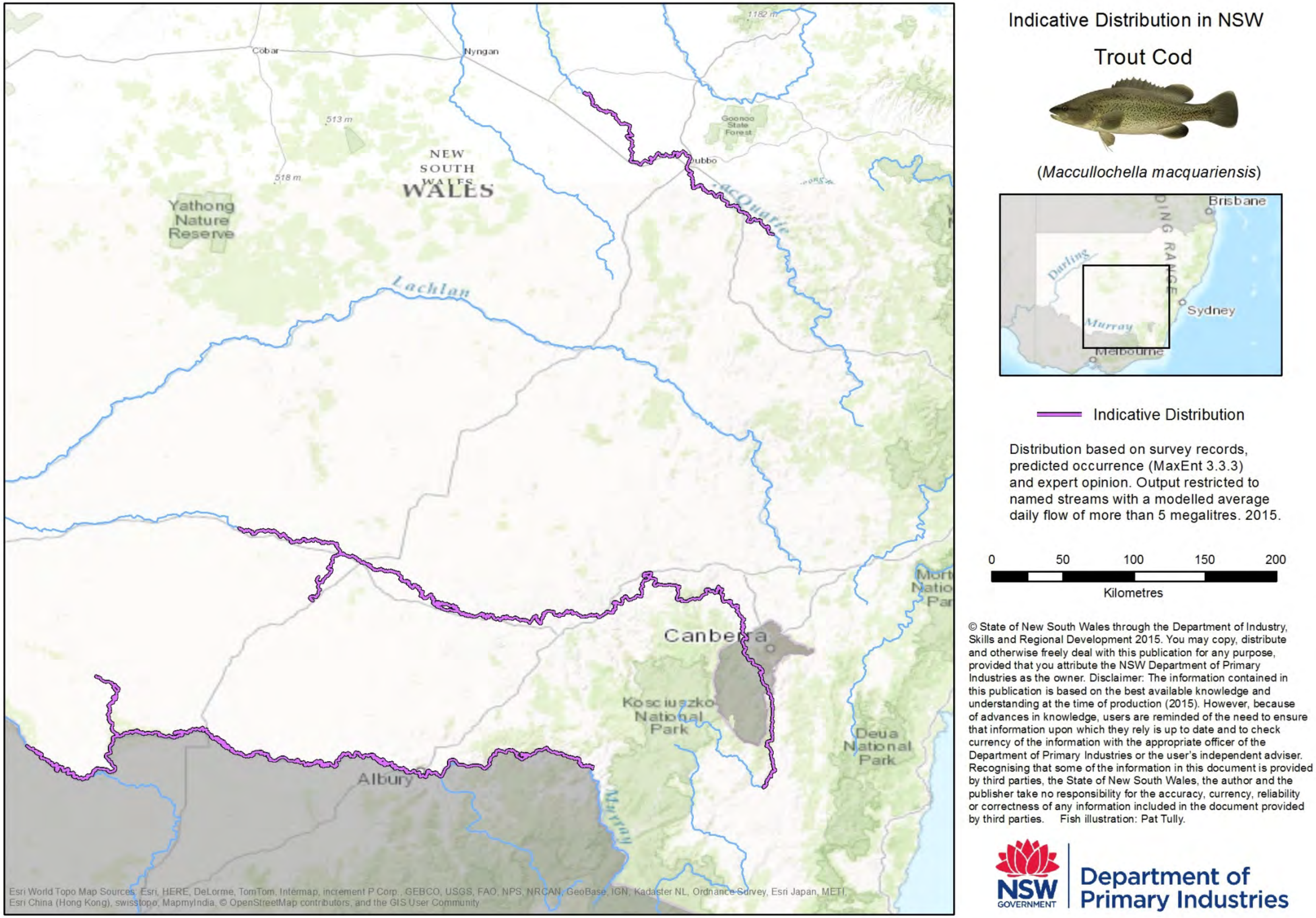


Figure 18 - Indicative distribution of the Trout Cod *Maccullochella macquariensis*



Appendix C – Environmental Attributes derived from the National Stream Attributes database version 1.1.5 (Stein et al. 2011) and utilised as relevant variables

Lookup Table	Attribute	Attribute Code	Definition	Original source dataset
Climate	Stream and environs average coldest month minimum temperature	STRCOLDMTHMIN	Average value of BIOCLIM parameter "Coldest month minimum temperature" of all grid cells comprising the stream segment and associated valley bottoms	9" DEM of Australia version 3 (2008) / ANUCLIM (Fenner School)
Climate	Stream and environs average hottest month maximum temperature	STRHOTMTHMAX	Average value of BIOCLIM parameter "Hottest month maximum temperature" of all grid cells comprising the stream segment and associated valley bottoms	9" DEM of Australia version 3 (2008) / ANUCLIM (Fenner School)
Landuse	Catchment average population density	CATPOPMEAN	Average population density of all grid cells upstream of the stream segment pour-point cell	ABS Population density within 2006 Australian Standard Geographic Classification census collector districts (compiled by University of Melbourne)
Landuse	Proportion of catchment with landuses where fertilzer is likely to be used	CAT_FERT	Areal proportion of the grid cells comprising the stream segment and its catchment upstream of the center of the stream segment pour-point cell with specified landuse category. Categories were formed from the tertiary landuse classification (M.Stewardson	Catchment Scale Land Use Mapping for Australia Update April 2009 (CLUM Update 04/09)
Landuse	Proportion of catchment with landuses where herbicides/pesticides is likely to be used	CAT_PEST	Areal proportion of the grid cells comprising the stream segment and its catchment upstream of the center of the stream segment pour-point cell with specified landuse category. Categories were formed from the tertiary landuse classification (M.Stewardso	Catchment Scale Land Use Mapping for Australia Update April 2009 (CLUM Update 04/09)
NPP	Annual mean Net Primary Productivity	NPPBASEANN	Annual mean Net Primary Productivity	Raupach et al (2002)
RDI-Geodata2	Segment Flow Regime Disturbance Index	SFRDI	River Disturbance Indices and Factors derived using the method of Stein et al (2002) and Stein et al. (1998).	Original source data detailed in Stein et al 1998 updated with 1. Catchment Scale Land Use Mapping for Australia Update April 2009 (CLUM Update 04/09), 2. Geodata TOPO 250K series 2 (Geoscience Australia, 2003), 3. Integrated Vegetation Cover (BRS, 2009)
runy1-yn	Coefficient of variation of annual totals of accumulated soil water surplus	RUNANNCOFV	Coefficient of Variation of the annual totals of the monthly accumulated soil water surplus values at the stream segment pour-point	Fenner School
runy1-yn	Coefficient of variation of monthly totals of accumulated soil water surplus	RUNMTHCOFV	Coefficient of Variation of the monthly totals of the accumulated soil water surplus values at the stream segment pour-point	Fenner School

Lookup Table	Attribute	Attribute Code	Definition	Original source dataset
runy1-yn	Monthly mean of accumulated soil water surplus for April	RUNAPR	Mean of the accumulated monthly total of the soil water surplus values at the stream segment pour-point for the years 1971-2000	Fenner School
runy1-yn	Monthly mean of accumulated soil water surplus for January	RUNJAN	Mean of the accumulated monthly total of the soil water surplus values at the stream segment pour-point for the years 1971-2000	Fenner School
runy1-yn	Monthly mean of accumulated soil water surplus for July	RUNJUL	Mean of the accumulated monthly total of the soil water surplus values at the stream segment pour-point for the years 1971-2000	Fenner School
runy1-yn	Monthly mean of accumulated soil water surplus for October	RUNOCT	Mean of the accumulated monthly total of the soil water surplus values at the stream segment pour-point for the years 1971-2000	Fenner School
runy1-yn	Pereniality	RUNPERENIALITY	Percent contribution to mean annual discharge by the six driest months of the year	Fenner School
Terrain	Maximum slope in downstream flow path	DOWNMAXSLP	Maximum slope from one grid cell to the next in the direction of flow downstream to the stream outlet. At stream bifurcations direction is always that to the main channel	9" DEM of Australia version 3 (2008)
Terrain	Mean segment elevation	STRELEMEAN	Mean elevation value of all grid cells comprising the stream segment	9" DEM of Australia version 3 (2008)
Terrain	Stream segment slope	VALLEYSLOPE	The slope of the stream segment calculated as the stream segment elevation range / length of segment.	9" DEM of Australia version 3 (2008)

Appendix D: MaxEnt parameters and output values for each species

Species	Population modelled	Valid spatial locations post 1/1/94	Categorical river type classification used.	Regularisation parameter (β)	Background segments used	Sampling bias correction	AUC (± SD)
Olive perchlet (*Ambassis agassizii*)	Murray-Darling Basin	29	Riverstyle	1.5	1,962	Sampled reaches only	0.859 ± 0.12
Adam's emerald green dragonfly (*Archaeophya adamsi*)	Hawkesbury-Nepean	6	AHGFFType	2	7,375	None	0.806 ± 0.329
Sydney hawk dragonfly (*Austrocordulia leonardi*)	All catchments from Karuah to Port Hacking	6	AHGFFType	1	10,000	Reach length corrected	0.726 ± 0.380
Alpine redspot dragonfly (*Austropetalia tonyana*)	All catchments from Goiulburn to Murrumbidgee in MDb and Yarra to Snowy on south-east coast.	5	AHGFFType	3	10,000	Reach length corrected	0.983 ±0.016
Silver perch (*Bidyanus bidyanus*)	Murray-Darling Basin	210	AHGFFType	2	3,173	Sampled reaches only	0.823 ± 0.018
Buchanan's fairy shrimp (*Branchinella buchananensis*)	Murray-Darling Basin	10	AHGFFType	1	2,699	Sampled reaches only	0.985 ± 0.022
Darling River hardyhead (*Craterocephalus amniculus*)	Murray-Darling Basin & Hunter	32	AHGFFType	1.5	3,350	Sampled reaches only	0.973 ± 0.018
Murray hardyhead (*Craterocephalus fluviatilis*)	Murray-Darling Basin	50	AHGFFType	1	3,200	Sampled reaches only	0.964 ± 0.037
Murray crayfish (*Euastacus armatus*)	Murray-Darling Basin	120	Riverstyle	7	1,965	Sampled reaches only	0.888 ± 0.037
Fitzroy Falls Spiny crayfish (*Euastacus dharawalus*)	Shoalhaven	5	Riverstyle II	1	5,460	None	0.995 ± 0.003
SEC River blackfish (*Gadopsis marmoratus*)	South-east coast population (La Trobe to East Gippsland catchments)	51	AHGFFType	1.5	10,000	Reach length corrected	0.959 ± 0.016
Flat-headed galaxias (*Galaxias rostratus*)	Murray-Darling Basin	22	AHGFFType	2	3,170	Sampled reaches only	0.866 ± 0.091
Macquarie perch (*Macquaria*	Hawkesbury to	46	Riverstyle II	1	5,993	None	0.937 ± 0.041

Species	Population modelled	Valid spatial locations post 1/1/94	Categorical river type classification used.	Regularisation parameter (β)	Background segments used	Sampling bias correction	AUC (± SD)
***australasica*) – east coast populations**	Shoalhaven (excluding Mongarlowe River)						
Macquarie perch (*Macquaria australasica*) – Murray-darling Basin population	Murray-Darling Basin	64	Riverstyle	2.5	1,961	Sampled reaches only	0.947 ± 0.032
Eastern cod (*Maccullochella ikei*)	Tweed to Clarence	88	Riverstyle	1	7,422	None	0.938 ± 0.029
Trout cod (*Maccullochella macquariensis*)	Murray-Darling Basin	60	Riverstyle	2	1,962	Sampled reaches only	0.943 ± 0.014
Southern purple-spotted gudgeon (*Mogurnda adspersa*) – coastal populations	Burnett to Bellinger	51	AHGFFType	1.5	10,000	Reach length corrected	0.907 ± 0.055
Southern purple-spotted gudgeon (*Mogurnda adspersa*) – Murray-Darling Basin populations	Murray-Darling Basin	31	Riverstyle II	2.5	1,962	Sampled reaches only	0.913 ± 0.091
Southern pygmy perch (*Nannoperca australis*)	Murray-Darling Basin	37	Riverstyle II	2.5	1,961	Sampled reaches only	0.946 ± 0.045
Oxleyan pygmy perch (*Nanoperca oxleyana*)	Fraser Island/Burrum River to Clarence	41	AHGFFtype	1	10,000	Reach length corrected	0.976 ± 0.029
River snail (*Notopala sublineata*)	Murray-Darling Basin	0					
Hanley's river snail (*Notopala hanleyi*)	Murray-Darling Basin	0					
Freshwater catfish (*Tandanus tandanus*) – Murray-Darling Basin populations	Murray-Darling Basin	164	Riverstyle	4.5	1,963	Sampled reaches only	0.838 ± 0.039

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