Shrinking habitats: **The future of the platypus** in a changing climate

AUSTRALIAN CONSERVATION FOUNDATION

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We acknowledge the Traditional Owners of this country and their continuing connection to land, waters and community. We pay respect to elders both past and present.

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Photo. Doug Gimesy

Executive **summary**

The platypus is an iconic Australian animal that lives across the eastern waterways of Australia, from north Queensland to Tasmania.

But Australian waterways are being dramatically impacted by climate change through the drying out of river systems and more extreme weather events.

This report examines the distribution of platypuses under current climate conditions and uses climate data to model how platypus habitat and population could change under different scenarios.

The modelling revealed worrying trends. Model projections show platypuses could lose up to 34% of suitable habitat towards the end of the century if climate change continues on the current trajectory. In an absolute worst-case climate scenario, projections show the area of platypus habitat would be reduced by more than three-quarters towards the end of this century compared to its original extent.

The projections do show an increase in suitable climate for platypuses around southern Victoria and into South Australia. However, the modelling does not account for existing threats that are already driving platypus decline, such as land management practices and declining water quality. Expansion of platypus' distribution into more suitable southern habitats also needs land management to be conducive to their dispersal and population.

Importantly, geographical areas that remain highly suitable even under a severe climate change future, such as those in coastal areas of northern and central New South Wales, are likely to be important refugial areas.

This report highlights the need for urgent action to protect climate refugia for platypuses — to give them the best chance of survival.

Introduction

Climate change has impacted all aspects of life, from genes to communities, and across all ecological biomes (Scheffers *et al.*, 2016).

Investigating the likely future impacts of climate change on species and populations is broadly done through species distribution modelling, which finds a relationship between the species and the environmental variables that characterise its environment.

Investigating the likely future impacts of climate change on species and populations is broadly done through species distribution modelling, which finds a relationship between the species and the environmental variables that characterise its environment. This relationship represents the species' climatic niche. Using future climate change scenarios, we can make a reasonable estimation of where the species' climatic conditions – and therefore habitat – might occur in the future. This modelling approach has been used for many species globally (Hof *et al.*, 2018), and the process of refining the methods to increase model accuracy is rapidly progressing (Forester *et al.*, 2013, Araújo *et al.*, 2019). The distribution modelling approach can provide some insight into future prospects for species, however to truly understand species' futures there are other methods that account for species' physiological and behavioural adaptability. These detailed methods are unfortunately extremely data intensive, and so are unavailable for most species. Where the time series distribution data exist, the distribution modelling approach has been shown to accurately predict where species will move to due to climate change (Tingley *et al.*, 2009).

Projections of species' likely distributions under climate change are widely used in conservation applications, such as identifying climate refugia (Reside *et al.*, 2018, Reside *et al.*, 2017, Reside *et al.*, 2013), and possible new areas for translocation (Butt *et al.*, 2020). Ideal climate refugia include areas of current habitat that remain suitable even under severe climate scenarios, which negate issues associated with dispersal to new habitats (Reside *et al.*, 2014). Additionally, there is high uncertainty with future projections of climate, therefore areas that are currently suitable and likely to remain so are the safest bet (Reside *et al.*, 2018). Species distribution modelling can help identify these areas (Reside *et al.*, 2013).

In addition to the uncertainty of the physical changes that might occur due to climate change (which can be difficult to predict at each location due to climate system feedbacks), uncertainties also surround species' individual responses to these changes, and the consequences of changing species interactions (Beaumont *et al.*, 2008). These uncertainties can be accounted for in multiple ways, by quantifying the different sources of uncertainty, and minimising it where possible (Reside *et al.*, 2018). Importantly, using a broad range of General Circulation Models (GCMs), which are the models used to predict

Photos. Doug Gimesy

the changes to climate in the future, we can find the range of potential climate responses, and find a middle ground (e.g., the median across many models) which is likely to be closer to how the future climate will manifest. Importantly, while accounting for uncertainty is very important, studies have found that conservation action early in the piece can maximize chances of achieving conservation targets, despite high uncertainty (Naujokaitis-Lewis *et al*., 2018).

The platypus (Ornithorhynchus anatinus) is an iconic Australian species, unique phylogenetically, ecologically, and evolutionarily. Platypuses occur across the eastern waterways of Australia from north Queensland to Tasmania, and have been found to survive in habitats even as they become degraded. However, some declines have been detected, particularly in South Australia, Victoria and New South Wales (Grant and Temple-Smith, 2003). Much of the waterways of south-eastern Australia have been highly modified through land and water management, and with the combined pressure of climate change (Bunn *et al*., 2006, Capon *et al*., 2013, James *et al*., 2013, James *et al*., 2017), investigation of the platypus populations and their trajectories throughout the range would be prudent.

This report outlines the approach to modelling the distribution of platypuses under current climate conditions, and the projection of the distribution onto multiple climate change futures (using established and new climate projection data). The output distribution models do not take into account non-climate conditions, such as land management or water quality. While these model outputs are intended to support conservation of platypuses, non-climate factors should also be accounted for in conservation decision making.

Platypuses could lose up to 34% of suitable habitat towards the end of the century

Photo. Pete Walsh

Methods

Platypus records

Platypus distribution data was sourced from the Atlas of Living Australia in 2012, the Queensland Museum and the CSIRO biodiversity database. All occurrence records went through a rigorous vetting process, which involved removing any records that fell within states, territories and IBRA bioregions in which platypuses do not occur. Incorporating expert assessment of species distribution modelling outputs has been shown to dramatically increase the accuracy of the output models, by picking up geographic and historical nuance that the algorithms have not accounted for (Reside *et al*., 2019). Records before 1950 were not used because the location was often inaccurate or imprecise. Vetted occurrence records were standardized to 0.01 degrees resolution (e.g., one occurrence per grid cell) so that only unique geolocations were used. After the vetting, there were 3,949 platypus presence records used in the model.

Climate records

Climate variables that have been shown to be important for Australian vertebrates in distribution models (Reside *et al*., 2013) were used: annual mean temperature, temperature seasonality, maximum temperature of warmest month, minimum temperature of coldest month, annual precipitation, precipitation seasonality, precipitation of wettest quarter, and precipitation of driest quarter. We accessed historical climate data and future climate data based on the IPCC Sixth Assessment Report CMIP6 through the WorldClim database (www.worldclim.org). The spatial surfaces for these climate variables were downscaled to 0.01 degrees (approximately 1 km x 1 km) resolution.

Modelling method

Platypus distribution models were run using Maxent (Phillips *et al*., 2006), as it is the most widely used species distribution modelling algorithm, consistently providing robust models (Elith *et al*., 2006). Maxent was run with a 10-fold cross validation, fitted with baseline climate data which were the 30-year average across 1976 and 2005. Maxent uses background points in order to distinguish between presence and absence of the modelled species, and the default is to use 10,000 random background points. However, using random background points assumes that there is no bias to the occurrence data. Unfortunately, unbiased datasets are rare, so to account for potential bias in the occurrence data, a 'taxon-specific target group background' was used. Here, all the occurrence points for terrestrial Australian mammals were used as background points, so that the same bias is likely to occur in the background points as in the occurrence points (Phillips *et al*., 2009).

The Maxent modelling output is a continuous suitability score for each pixel, between 1 (most suitable) and 0 (least suitable). Determining the cut-off for what is sufficiently unsuitable for the species to not occur in an area is done by picking a threshold score, and can be calculated through multiple methods. We mapped four different suitability score thresholds, and picked the one that most accurately represented platypus distribution by balancing risk of omission (leaving out areas in which they actually do occur) and commission (leaving in areas in which they do not occur) errors (Graham *et al*., 2019).

Model performance was evaluated using the area under the receiver operating characteristic curve (AUC) statistic, which is a useful evaluation unless the species occurs across the entire background area (e.g., every grid cell in Australia, because the model algorithm cannot distinguish from presence and absence locations) (Reside *et al*., 2011). AUC scores greater than 0.7 indicate a useful model (Lobo *et al*., 2008).

Waterways are dramatically impacted by climate change **through drying river systems and more extreme weather events.**

Future climate projections

We compared two sets of future projections: data from the the Representative Concentration Pathways (RCPs; Rogelj *et al*., 2012) which supported the IPCC Fifth Assessment Report (IPCC, 2014), and the Shared Socioeconomic Pathways (SSPs), which incorporate different possible socioeconomic developments (Riahi *et al*., 2017). The two sets of data are useful because the Representative Concentration Pathways (RCPs) projections are long-accepted, and methods extensively published on, while the SSP data are relatively new and not as extensively used for species modelling yet. The two RCPs, or greenhouse gas concentration trajectories used were RCP 4.5, representing an emissions peak around 2040 and RCP 8.5, where emissions continue to rise throughout the 21st century (Rogelj *et al*., 2012). Eighteen General Circulation Models (GCMs; Appendix 1) were used to generate suitable habitat predictions for six time points into the future: 2035, 2045, 2055, 2065, 2075 and 2085.

The two Shared Socioeconomic Pathways used here were SSP2 and SSP5 (Riahi *et al*., 2017). SSP2 represents a business as usual pathway, this pathway adopts the representative concentration pathway (RCP) 4.5 and projects forwards historical patterns of development (Fricko *et al*., 2017). SSP5 represents a fossil-fueled development pathway, this pathway adopts RCP 8.5, an optimistic trend for human development, with substantial investments in education and health, rapid economic growth, and well-functioning institutions. The SSP5 pathway will be driven by an energy-intensive, fossil fuel-based economy (Kriegler *et al*., 2015). Eight global climate models (GCMs) were used to generate suitable habitat predictions (BCC-CSM2-MR, CNRM-CM6-1, CNRM-ESM2-1, CanESM5, IPSL-CM6A-LR, MIROC-ES2L, MIROC6, MRI-ESM2-0), across four time-periods (2030, 2050, 2070 and 2090).

These projections indicate all areas in the future with suitable climate conditions, however it is unlikely that platypuses could disperse to wherever climate became suitable, due to various intrinsic and extrinsic constraints on their dispersal abilities (Mair *et al*., 2014). We dealt with this by only retaining areas modelled to be suitable if they were within 40 km of where platypuses had occurred in the last decade (therefore, allowing them an optimistic dispersal distance of 4 km per year) (Warren *et al*., 2013). For each decadal projection, the future SDMs were clipped by the estimated maximum potential dispersal distance – only suitable areas within this maximum potential dispersal distance were retained. This process produced a large number of model outputs (for the RCP models: 18 GCMS x 4 RCPs x 6 decades = 432; for the SSP models: 8 GCMs x 2 SSPs x 5 time periods = 80; therefore, 512 in total). Therefore we summarised the outputs across the GCMs for each RCP and again for each combination of GCM and SSP, and each time period; these summaries were the 10th, 50th, and 90th percentiles. The percentile summaries illuminate the variation and extremes across the GCMs.

Further constraints exist for where platypuses can occur, as they are dependent on waterways. To generate a more realistic representation of the extent of habitat available to platypuses, we intersected the river and stream network with the gridded climate suitability models. We used the HydroSHEDS data (Lehner and Grill, 2013), which is derived from 15 arc-second digital elevation model (c. 500 m at the equator). Therefore, we only counted a grid cell as suitable platypus habitat if it had both suitable climate and contained a river or stream (Appendix 4).

The platypus is an iconic Australian species. It is unique ecologically and evolutionarily.

Results

Model output results

The model statistics found the model to perform well: Regularized training gain was 0.646, training AUC was 0.814, unregularized training gain was 0.736. A total of 3,949 presence records were used for training, and a total of 109,992 points were used to determine the Maxent distribution (background points and presence points).

The input climatic variable that had the greatest influence on the model (72.3%) was precipitation of the driest quarter, which indicates that the model did a reasonable job of finding areas that receive sufficient rainfall in the driest parts of the year to sustain platypus habitat (Table 1).

Suitable platypus habitat requires precipitation of the driest quarter to be from 50–200 mm, as shown in the variable response curves (Figure 2). Interestingly, suitable habitat aligns with low precipitation seasonality (i.e., low variation in rainfall across the year).

Table 1: The climate variables used in the model, and their contribution to the model. There are annual variables (e.g., mean annual temperature, annual precipitation), seasonality variables (e.g., the annual range in temperature and precipitation), and extreme or limiting environmental factors (e.g., temperature of the coldest and warmest month, and precipitation of the wet and dry quarters). A quarter is a period of three months (1/4 of the year). For more information see the WorldClim website https://www.worldclim.org/data/bioclim.html

Variable	Bioclim code	% contribution to the model	Permutation importance
Precipitation of the driest quarter	Bioclim 17	72.3	7.8
Temperature seasonality (standard deviation x 100)	Bioclim 04	8.2	18.8
Max temperature of warmest month	Bioclim 05	7.2	15.1
Min temperature of coldest month	Bioclim 06	4.4	14.5
Precipitation of wettest quarter	Bioclim 16	3.5	7.4
Annual mean temperature	Bioclim 01	2.1	7.5
Annual precipitation	Bioclim 12	1.2	16.7
Precipitation seasonality (coefficient of variation)	Bioclim 15	1.1	12.1

Figure 1: The response curve plots for each variable, demonstrating suitability for platypuses across the range of each of the climate variables.

Distribution output

The output distribution model shows platypus habitat stretching from the Wet Tropics bioregion of Far North Queensland, throughout the east coast down to Tasmania (Figure 2, left panel). There are areas of marginal suitability on the inland fringe of the distribution from southern Queensland to South Australia.

The future climate change projections for both the RCP and SSP data gave remarkably similar outputs (Figure 2 and Appendix 5). From here on the main text will focus on the SSP output, with the RCP output in the Appendices, for reference. The future projections of suitable habitat for platypuses show that the inland fringe of current habitat is likely to become unsuitable (Figure 2, centre panel). Areas of southern Victoria are projected to increase in suitability, and there may be areas from western Victoria to eastern South Australia that become suitable in the future. Areas that are currently modelled to be highly suitable that retain high suitability into the future, such as those along the most easterly coastal areas of northern New South Wales and throughout Tasmania, are likely places of key refugia.

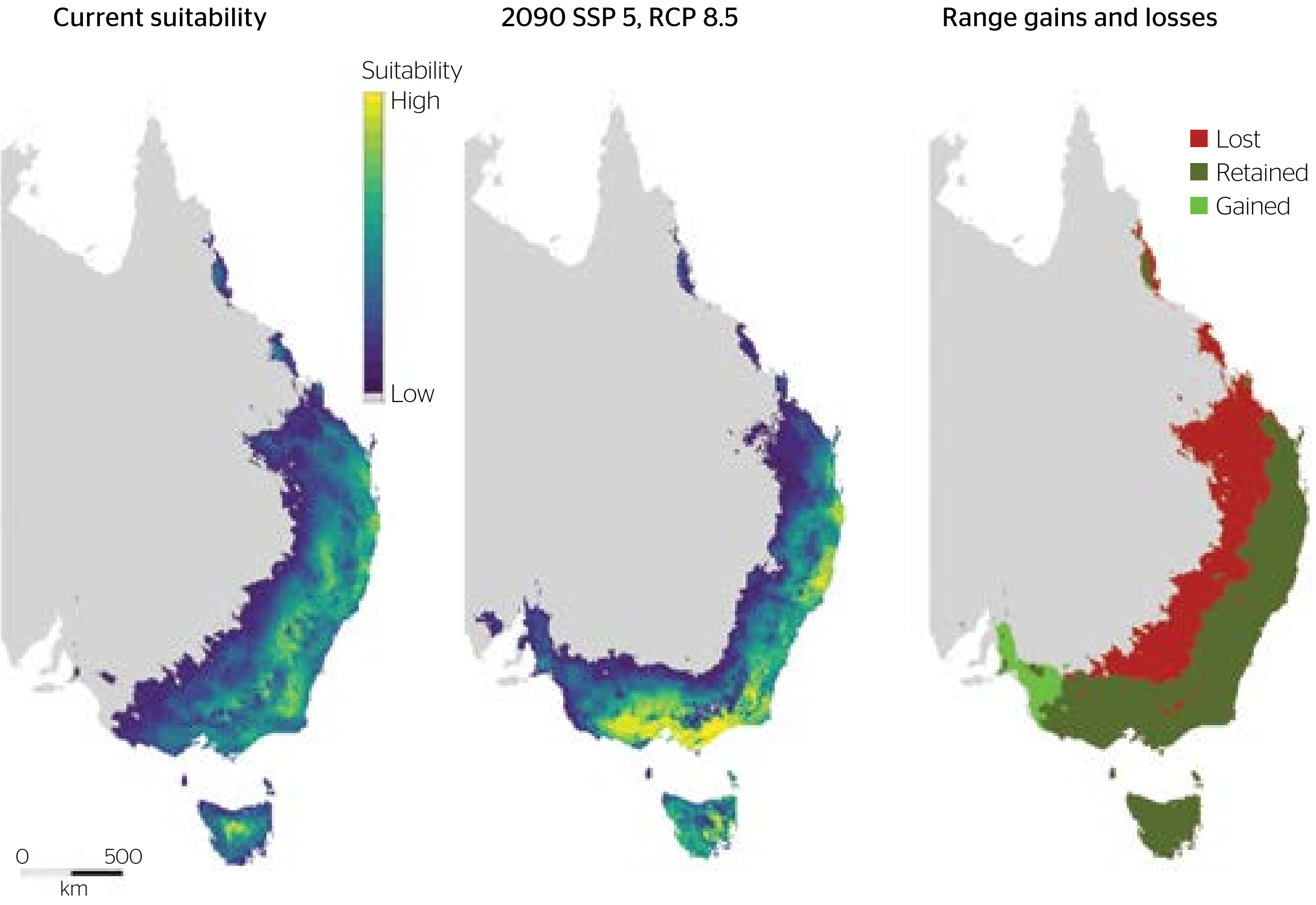

Figure 2: Maxent model output for the distribution of platypuses. Left: the distribution under current climate (baseline climate an average of conditions from 1976 to 2005). Centre: projections for platypus habitat for 2090 under SSP585. Right: the change from the current distribution to the projected future distribution in 2090, showing areas lost (red), gained (light green) and retained (dark green).

Area of distribution

After examining four different thresholds (Appendix 2), the threshold type that best fitted the model was "Balance training omission, predicted area and threshold value," with a threshold value of 0.094. All habitat suitability scores greater than 0.094 were deemed to be suitable for platypuses, and all scores below this were deemed unsuitable. After applying this threshold, we calculated the area of suitable climate space for platypuses. While we report here the area of all modelled suitable climate space, it is important to take into consideration how much actual habitat may be within this area. Importantly, given the dependence on waterways, the intersection of the stream network showed there to be 265,662 km² of suitable habitat currently, which is only one-quarter of that predicted without considering waterways. Furthermore, this is likely to be an over-estimate, given that the grid cells are 1x1 km, and many of the streams would be less than 100 m across.

The area of suitable climate space (intersected with waterways) was found to contract each decade under both SSPs, with only 226,963 km² found to be suitable by 2090 under SSP245, dropping to 174,676 km² by 2090 under SSP585 — a decline of 34% (Figure 3). The difference between the climate outcomes of a moderate climate change future (SSP245) and a more realistic climate change future (SSP585) are stark: by 2090 the area of suitable climate for platypuses drops substantially by over one-third under the realistic climate change future. This difference is even greater when considering the models run with the RCP projections (Appendix 3): by 2085 the area of suitable climate for platypuses drops substantially by almost half under the realistic (business-as-usual) climate change future. The absolute worst case scenario (RCP 8.5, with the 10th percentile across 18 GCMs) would find platypus habitat reduced by over three-quarters of its original extent (Table 2).

The uncertainty in model outcomes increases as the models are projected further into the future, as shown by the error bars in Figure 3. These error bars represent the percentiles across all GCMs, and by 2090 there is greater variation in the available climate space for platypuses across the different GCMs.

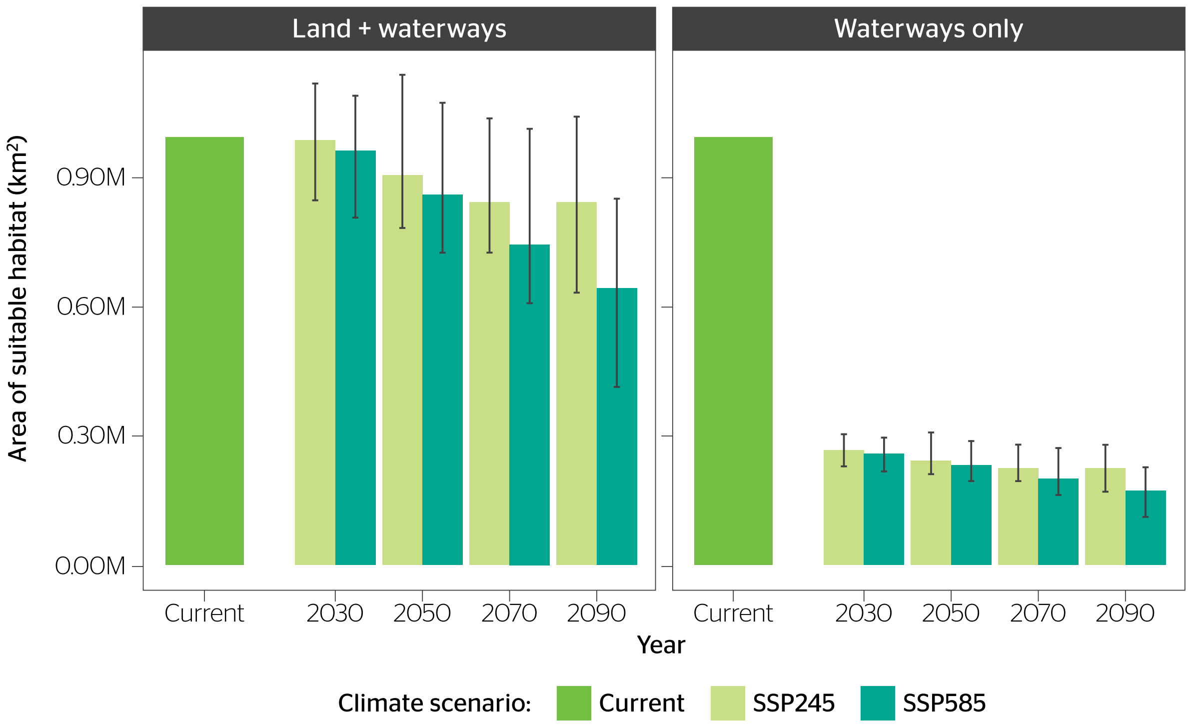

Figure 3: The area (km²) of suitable climate space for platypuses. The current area is shown in green on the left, the future projections for both SSP245 and SSP585 are shown in comparison. The blue and pink bars represent the 50th percentile across the 8 General Circulation Models for each decade; the error bars represent the 10th and 90th percentiles respectively.

Discussion

Model projections show that platypuses could lose up to 34% of their currently suitable habitat towards the end of the century if climate change continues on the current trajectory. In particular, areas that are currently marginally suitable on the inland edge of their range are the areas that are most likely to be lost. The central and south-east Queensland areas are also at high risk.

The modelling algorithm found precipitation of the driest quarter to be the variable most influential to the model, and that suitable platypus habitat requires low variation in rainfall across the year. Dry season rainfall could see decreases in many parts of Australia, and rainfall extremes (extreme dry and extreme wet) are predicted to increase. These factors, combined with increasing anthropogenic pressure on the coastal fringe of Australia where rainfall is the most reliable, are likely to impact where platypuses can survive.

The projections show an increase in suitable climate around southern Victoria and into South Australia. However, expansion of platypus distribution requires that the land management is conducive to their dispersal and population persistence. The models in this report take into account the platypuses current range and those climatic conditions, and where those climatic conditions are modelled to exist in the future, but do not account for land management and other non-climatic factors that influence water quality and food availability. These models could however, be used as a guide to detecting climate refugia for platypuses. Areas that are currently highly suitable, and that are modelled to continue to be suitable even under the most severe (and realistic) climate change future are the safest bet for climate refugia.

Table 2: Changes in predicted area of suitable habitat. The current area of suitable habitat (calculated by suitable climate space where there are waterways) is 265,662 km². (Suitable climate space only is 987,467 km²). Under SSP245 and SSP585, the median (50th percentile) area of suitable habitat is predicted to decrease each decade from 2030 to 2090. To show the range of model results, 10th and 90th percentiles are also shown. "All suitable climate space" includes areas of land that do not contain waterways, and so overestimates the amount of suitable habitat. "Waterways within suitable climate space only" clips that area so that it only includes grid cells that intersect with a waterway.

	All suitable climate space			Waterways within suitable climate space only		
Year	**10th**	**50th**	**90th**	**10th**	**50th**	**90th**
SSP 245						
2030	847,794	986,175	1,117,351	230,390	267,380	304,214
2050	781,863	904,401	1,136,115	212,410	244,591	308,545
2070	725,479	843,098	1,036,108	197,252	228,188	280,522
2090	631,905	839,596	1,040,604	172,779	226,963	281,692
SSP 585						
2030	805,807	961,570	1,089,827	218,358	260,527	296,297
2050	726,293	860,418	1,071,633	197,587	232,509	290,002
2070	606,300	744,505	1,013,752	165,435	201,406	274,239
2090	415,617	644,002	849,258	113,524	174,676	229,112

Photo. Doug Gimesy

We need to protect climate refugia for platypuses to give them **the best chance of survival**

Photo. Pete Walsh

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Australian waterways are being dramatically impacted by climate change

Appendices

Appendix 1.

The General Circulation Models used for the climate projections.

Abbreviation	Agency	Model Name
cccma-cgcm31	Canadian Centre for Climate Modelling and Analysis (CCCma), Canada	Coupled Global Climate Model (CGCM3)
ccsr-miroc32hi	Centre for Climate System Research, University of Toyko, Japan	Model for Interdisciplinary Research on Climate, version 3.2 – High resolution
ccsr-miroc32med	Centre for Climate System Research, University of Toyko, Japan	Model for Interdisciplinary Research on Climate, version 3.2 – Medium resolution
cnrm-cm3	Centre National de Recherches Meteorologiques, Meteo France, France	CNRM-CM3
csiro-mk30	Commonwealth Scientific and Industrial Research Organisation, Australia	CSIRO Mark 3.0
gfdl-cm20	Geophysical Fluid Dynamics Laboratory, NOAA, USA	CM2.0 - AOGCM
gfdl-cm21	Geophysical Fluid Dynamics Laboratory, NOAA, USA	CM2.1 - AOGCM
giss-modeleh	Goddard Institute for Space Studies, NASA, USA	GISS ModelE-H
giss-modeler	Goddard Institute for Space Studies, NASA, USA	GISS ModelE-R
iap-fgoals10g	LASG, Institute of Atmospheric Physics, Chinese Academy of Sciemces, P.R. China	FGOALS1.0_g
inm-cm30	Institute of Numerical Mathematics, Russian Academy of Science, Russia	INMCM3.0
ipsl-cm4	Institut Pierre Simon Laplace (IPSL), France	IPSL-CM4
mpi-echam5	Max Planck Institute for Meteorology, Germany	ECHAM5/MPI-OM
mri-cgcm232a	Meteorological Research Institute, Japan Meteorological Agency, Japan	MRI-CGCM2.3.2
ncar-ccsm30	National Center for Atmospheric Research, USA	Community Climate System Model, version 3.0 (CCSM3)
ncar-pcm1	National Center for Atmospheric Research, National Science Foundation, Department Of Energy, NASA, and NOAA, USA	Parallel Climate Model (PCM)
ukmo-hadcm3	Hadley Centre for Climate Prediction and Research, Met Office, United Kingdom	HadCM3
ukmo-hadgem1	Hadley Centre for Climate Prediction and Research, Met Office, United Kingdom	Hadley Centre Global Environmental Model, version 1 (HadGEM1)

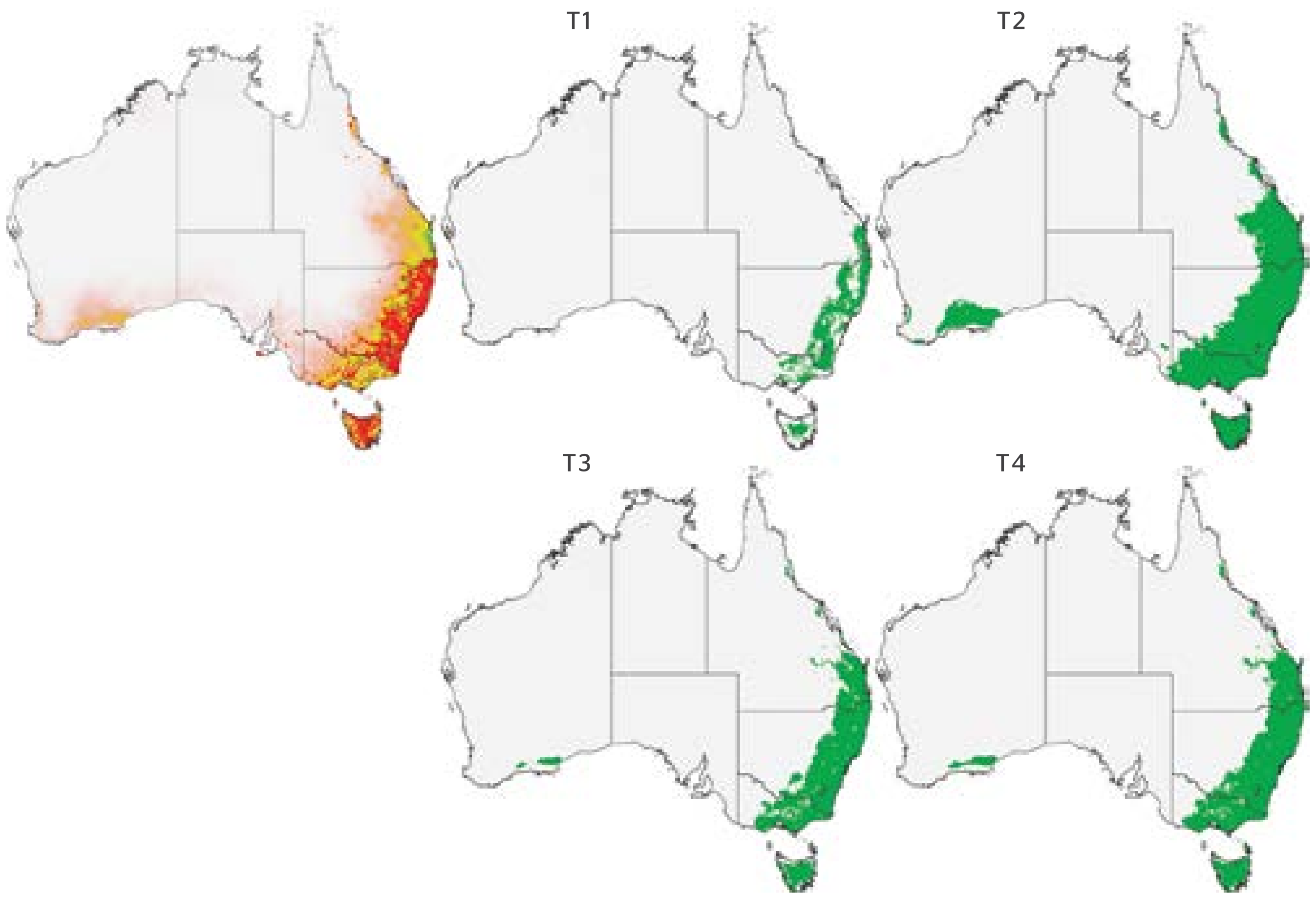
Appendix 2.

The maxent model output distribution for platypuses, with examination of four different thresholds.

Areas in which the model predicted to be climatically suitable, but which are currently outside the range (e.g. Western Australia) were masked out using states and IBRA bioregions in which the species does not occur.

Maxent modelling output is a continuous suitability score for each pixel, between 1 (most suitable) and 0 (least suitable). Determining the cut-off for what is sufficiently unsuitable for the species to not occur in an area is done by picking a threshold score, and can be calculated through multiple methods. We mapped four different suitability score thresholds, and picked the one that most accurately represented platypus distribution by balancing risk of omission (leaving out areas in which they actually do occur) and commission (leaving in areas in which they do not occur) errors (Graham *et al.*, 2019).

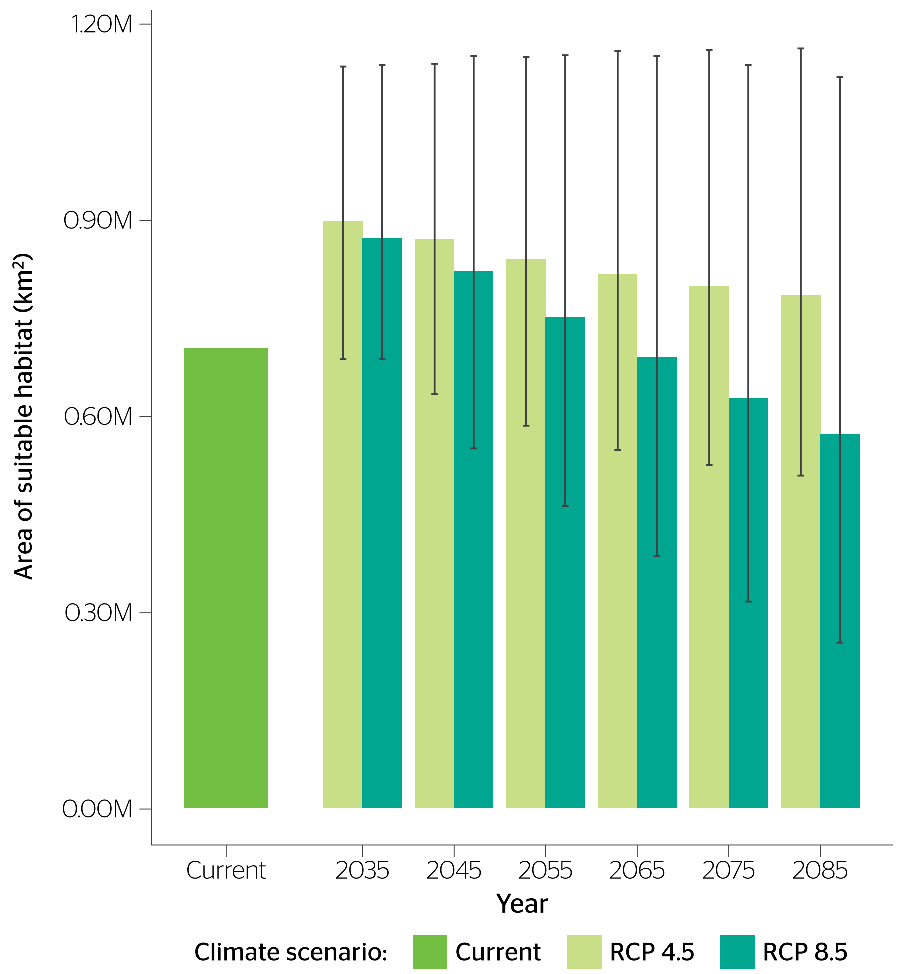
The three standard output thresholds generated from Maxent showed here are T1: Equal training sensitivity and specificity logistic threshold; T2: Balance training omission, predicted area and threshold value logistic threshold, T3: Equate entropy of thresholded and original distributions logistic threshold. In some cases of extreme over-fitting a high threshold was required, so for comparison, T4 was the highest threshold doubled.



Appendix 3.

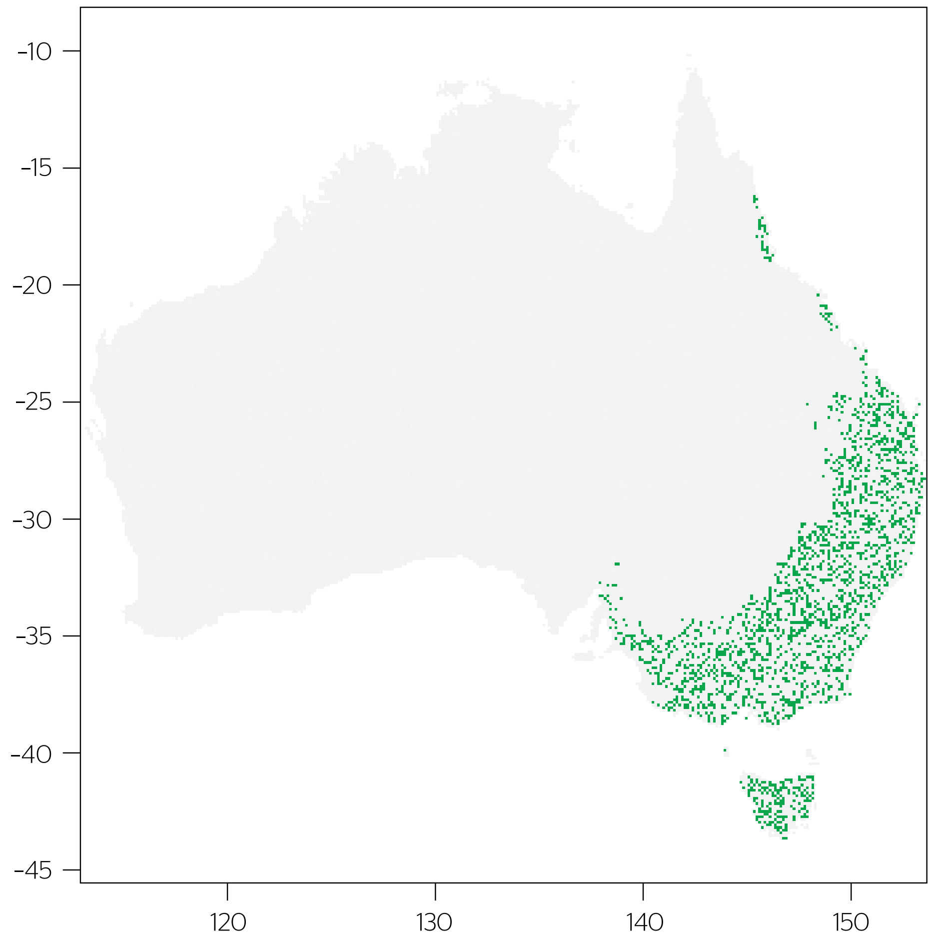
The area (km²) of suitable climate space for platypuses using RCP projections.

The current area is shown in green on the left, the future projections for both RCP4.5 and RCP8.5 are shown in comparison. The blue and pink bars represent the 50th percentile across the 18 General Circulation Models for each decade; the error bars represent the 10th and 90th percentiles respectively.



Appendix 4.

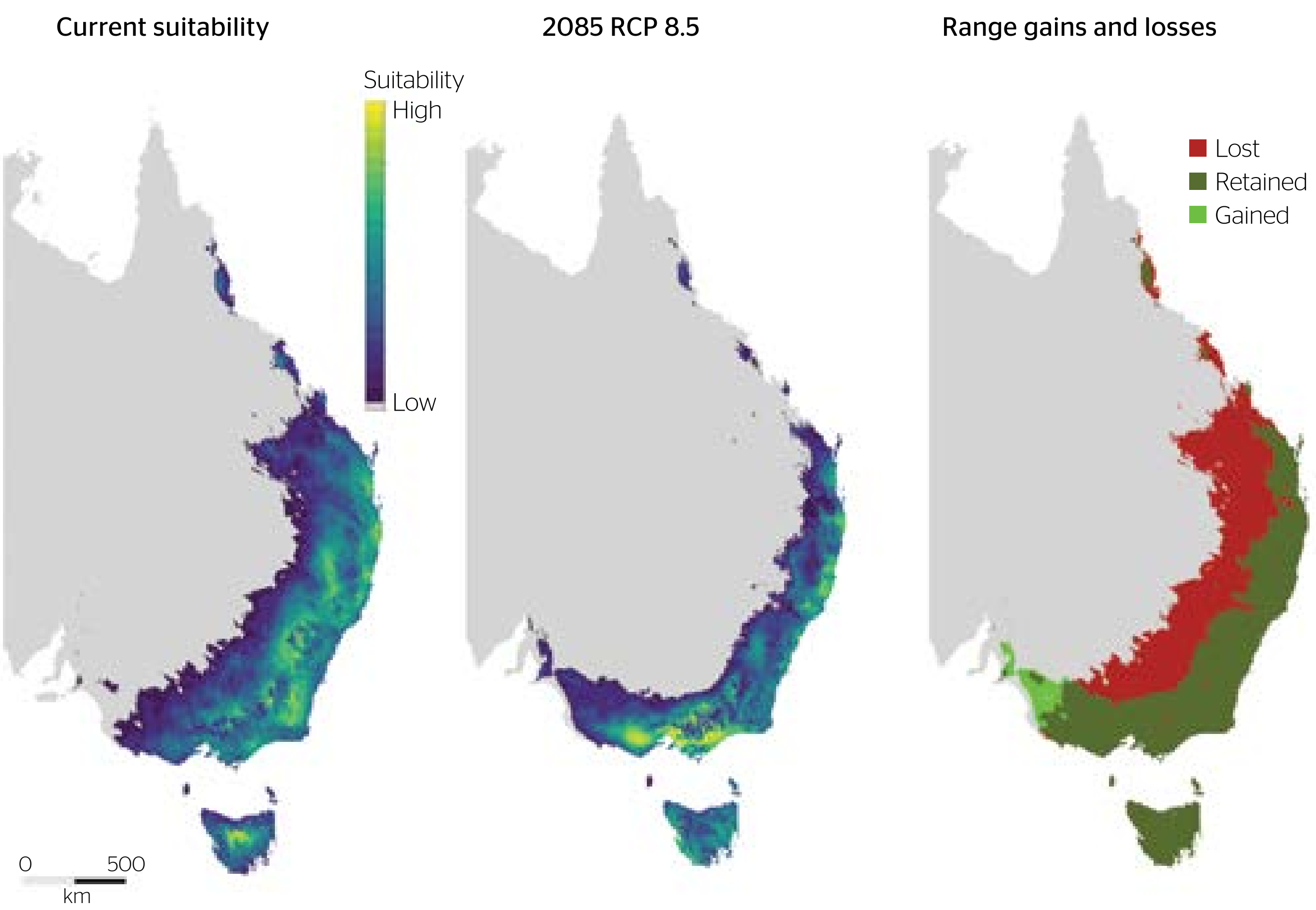
The stream network within the platypuses' modelled suitable climate space.



Appendix 5.

Maxent model output for the distribution of platypuses, with future projections based on RPC data.

Left: the distribution under current climate (baseline climate an average of conditions from 1976 to 2005). Centre: projections for platypus habitat for 2085 under RCP8.5. Right: the change from the current distribution to the projected future distribution in 2085, showing areas lost (red), gained (light green) and retained (dark green).



Appendix 6.

Changes in predicted area of suitable habitat.

The current area of suitable habitat is 987,467 km^2. Under RCP 4.5 and RCP 8.5, the median (50th percentile) area of suitable habitat is predicted to decrease each decade from 2035 to 2085. To show the range of model results, 10th and 90th percentiles are also shown.

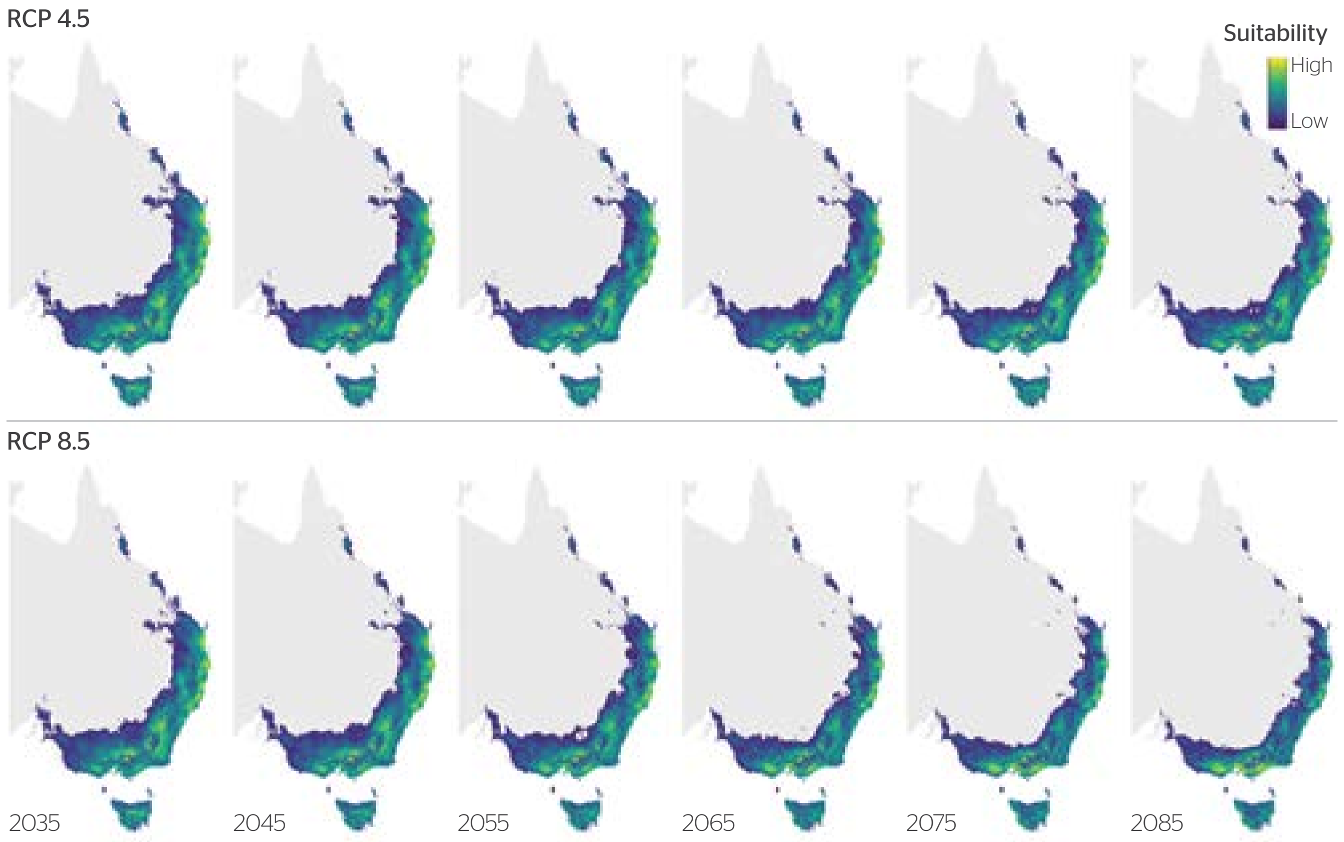
Year	10th percentile	50th percentile	90th percentile
RCP 4.5			
2035	687,421 km^2	900,588 km^2	1,135,438 km^2
2045	632,786	871,799	1,140,901
2035	584,978	841,739	1,150,730
2035	547,525	818,636	1,160,176
2075	523,974	800,755	1,162,557
2085	508,593	786,581	1,163,250
RCP 8.5			
2035	636,608 km^2	874,138 km^2	1,139,189 km^2
2045	549,765	822,323	1,152,361
2055	462,300	753,257	1,153,409
2065	384,688	691,174	1,152,294
2075	315,780	628,701	1,138,271
2085	252,524	571,664	1,119,815

Photo. Pete Walsh

Appendix 7.

Projected distribution of suitable climate space for platypuses for each decade, and both RCPs (4.5 and 8.5).

Distribution models shown here have been clipped so that areas lower than the threshold have been masked out.



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