A national assessment of the **conservation status of the platypus**

UNSW SYDNEY

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WWF

HUMANE SOCIETY INTERNATIONAL AUSTRALIA

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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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Executive summary

The platypus is an iconic Australia species which has faced an increasing number and intensity of threats since European colonisation. It is currently listed as 'Near Threatened' under the International Union for Conservation of Nature (IUCN) Red List but not currently listed as threatened under Australia's *Environment Protection and Biodiversity Conservation* (*EPBC) Act 1999*. The platypus is currently listed in South Australia as Endangered (*National Parks and Wildlife Act 1972*) and in Victoria it was listed as Vulnerable on the 10th of January 2021 (*Flora and Fauna Guarantee Act 1998)*. In this report we assessed the species' risk of extinction against IUCN and *EPBC* criteria. This is an updated report, with additional analyses to version 1.0, released in November 2020. We collated all available data relating to platypus observations from multiple sources. Based on our assessment, there is evidence of past and projected declines in platypus populations which support the listing of the platypus as **Vulnerable** under the IUCN Red List and the *EPBC Act 1999*. This conclusion is based on the following assessments for each of the eligible Criteria.

While the platypus is considered widespread, occupying an extensive range across eastern Australia, there are several lines of evidence that indicate declines in distribution and abundances. Given the lack of monitoring across large parts of the platypus' distribution, we relied on reported observation to infer declines. As platypus generation length is estimated to be seven years, this assessment examines declines since 2000 (i.e., 21 years 2000-2020). Atlas records suggest the lower bound estimate for platypus Area of Occupancy (AOO) over the last 21 years is 4,110 2x2 km grid cells (16,440 km^2). Within the last generation (2014-20), platypuses have only been reported in 1,397 cells (5,588 km^2). The upper bound estimate for the last three generations based on 2x2 km grid cells which overlap potential platypus habitat is 94,656 cells (378,624 km^2). Records also suggest a potential decline of 21.3% in Extent of Occurrence (EOO) of platypuses over the last 21 years. Presumed declines since 2000 have been greatest in the Gulf of Carpentaria (40.5%) and the Murray-Darling Basin (27.9%), within the states of QLD (29.6%) and NSW (28.5%). In peri-urban areas, some platypus populations across the greater Melbourne region have been estimated to have declined between 18-65% in abundance from 1995-2019, likely influenced by the Millennium Drought (2002-2009), though other populations near Melbourne are estimated to have increased by 76-92%. In the greater Brisbane region, there has been a 24% decline in the number of waterways platypuses inhabit since 1990. Between the 2000-06 and the 2014-20 time-periods, there has been a 10% decrease

in the proportion of habitat where platypuses were reported. Significant declines are inferred from synergistic threats across the distribution of the platypus, reducing habitat quality and increasing fragmentation. Population viability analyses predict a decline in effective minimum population sizes between 45.0% and 58.1% as a result of existing impacts of land clearing, river regulation and extreme droughts. As examined threatening processes began more than 50 years ago, but are still ongoing, modelled declines have likely already occurred but continue. Given that the causes for these declines have not ceased, and may continue to increase, and are not reversible in the foreseeable future, the proposed assessment of the platypus is **Vulnerable** under criterion **A2**.

Continued population reduction of platypuses is also projected in the future, based on threats and the impacts of climate change on rivers. Under projected increased frequency and duration of droughts, combined with fragmentation and habitat destruction, effective minimum population was predicted to further decrease between 4.4% and 13% by 2055 but is likely higher given the species' climatic niche may contract between 17% to 43% over this period. As drivers of these declines have not ceased, declines will likely continue, and are not reversible in the foreseeable future, the proposed assessment of the platypus is **Vulnerable** under criteria **A3** and **A4.**

Taxonomy

Taxon Name: *Ornithorhynchus anatinus* (Shaw, 1799)

Common Name(s): Platypus, Duck-billed Platypus

Synonym(s): Platypus anatinus (Shaw, 1799)

Kingdom	Phylum	Class	Order	Family
Animalia	Chordata	Mammalia	Monotremata	Ornithorhynchidae

IUCN threated species assessment status

Previously Published IUCN Red List Assessments:

2016 – Near Threatened (NT)

2008 – Least Concern (LC)

1996 – Lower Risk/least concern (LR/lc)

EPBC threatened species assessment status

The platypus is not currently listed as a threatened species on Australia's *EPBC Act 1999*. Besides South Australia, where is it listed as endangered (*National Parks and Wildlife Act 1972*), the platypus is not on the threatened species schedule for any other state where it occurs.

Species description

The semi-aquatic platypus is evolutionarily and morphologically unique, making it one of the most distinct and iconic mammals alive today. It is the only living species of the Ornithorhynchidae family and one of only five extant species of monotremes (Grant & Fanning 2007). Modern platypuses are endemic to eastern Australia, with the platypus lineage estimated to have originated at least 120 million years ago (Johnson 2006). Some of its main defining features are its duck-like bill, waterproof fur, webbed feet, and the calcaneus spurs on the hind ankles of males. Monotremes are also unique for egg laying and the use of electroreception to detect prey (Grant & Fanning 2007).

The platypus in indigenous culture

Aboriginal people have a dreamtime story from the upper reaches of the Darling River of the platypus (McKay et al. 2001), which begins with a young duck who disregarded her tribe's warning of Mulloka (or Waaway), the water devil. The duck, venturing down the creek far from her tribe, was abducted by Biggoon, a large water-rat who took the duck as his wife. The duck eventually escaped and returned to her tribe, where she laid two eggs which hatched as platypuses. They had soft fur instead of feathers, four webbed feet instead of two, and spurs on their hind legs, like Biggoon's spear. The duck and her two different children were banished by her tribe, choosing to live far away in the mountains where she could hide from her tribe and Biggoon. A second dreaming from the upper reaches of the Darling River (McKay et al. 2001) begins with the Ancestor Spirits deciding on totems. The birds, marsupials, and fish each implore the platypus to join their family. After consulting with the echidna, the platypus graciously declines, explaining that it shares traits with all groups and wishes to remain friends with all of them, rather than belong to one single group. The platypus commemorates the Great Spirit for making all the animals different and respecting its wisdom.

The platypus is also used by some First Nations as a totem. Paulson (2020) describes a totem as a 'natural object, plant or animal that is inherited by members of a clan or family as their spiritual emblem.' The platypus is known to hold specific cultural significance as a totem animal for members of the Wadi Wadi community along the Murray River (Simmons 2013). The conservation and protection of totems is important for ongoing connection to country and cultural practices. (Paulson 2020).

Utilization of taxon

Platypuses were hunted for food by Aboriginal people by digging them from their burrows or spearing them while swimming (Robinson & Plomley 2008) The platypus' tail is rich in fats may have been particularly important in cold conditions. Europeans hunted platypuses for their fur in the late 19th and early 20th century until it was legally protected in all Australian states by 1912.

The platypus was used as an instrument for early colonial naturalists to establish themselves as researchers, bring pride to their nation and outcompete rivals (Robin 2005). After European settlement of Australia, power and recognition was awarded to scientists who made the biggest discoveries to western science (Robin 2005). Relying on the traditional knowledge and skills of indigenous Australians, European researchers captured, killed, exported, and removed eggs from platypuses in the pursuit of scientific advancement (Robin 2005).

The platypus has also been used as a symbol of Australia's unique culture and national identity (Cushing and Markwell 2009). Live platypuses were gifted to Australia's wartime allies during the 1940s as diplomatic gestures to strengthen relations and improve morale during difficult times (Cushing and Markwell 2009). The platypus has been used in Australian post-colonial iconography, including featuring on stamps and currency and utilized as a mascot for the 2000 Sydney Olympic Games (White 2011).

Geographic Range

Countries of occurrence

Platypuses are endemic to eastern Australia in Queensland, New South Wales, Australian Capital Territory, Victoria, Tasmania, and South Australia.

Distribution

The distribution of the platypus in Australia spans from Cooktown in northern Queensland to Tasmania (Figure 1). In Queensland, platypuses are primarily distributed in eastern flowing rivers and waterways, but their distribution is limited elsewhere in the state. In New South Wales, platypuses are more common on the eastern side of the Great Dividing Range but do extend into western-flowing rivers and waterways of the Murray-Darling Basin (Grant & Fanning 2007). Platypuses are reasonably widespread throughout Victoria and Tasmania, occupying 26 of 31 river systems in Victoria (84%) and 15 of 19 river systems in Tasmania (79%), but there is evidence for population declines near metropolitan areas (Grant & Denny 1991). Platypuses are considered vulnerable in South Australia, with sporadic records throughout the Mount Lofty Ranges, Adelaide Hills. There is also an introduced population on Kangaroo Island (Grant & Denny 1991). The current IUCN distribution for platypuses spans 902,907 km^2. However, there are a number of platypus observations outside this distribution (Figure 1), suggesting that the potential range for platypuses might be greater than the current IUCN distribution, highlighting our knowledge gaps in the understanding of the species' range.

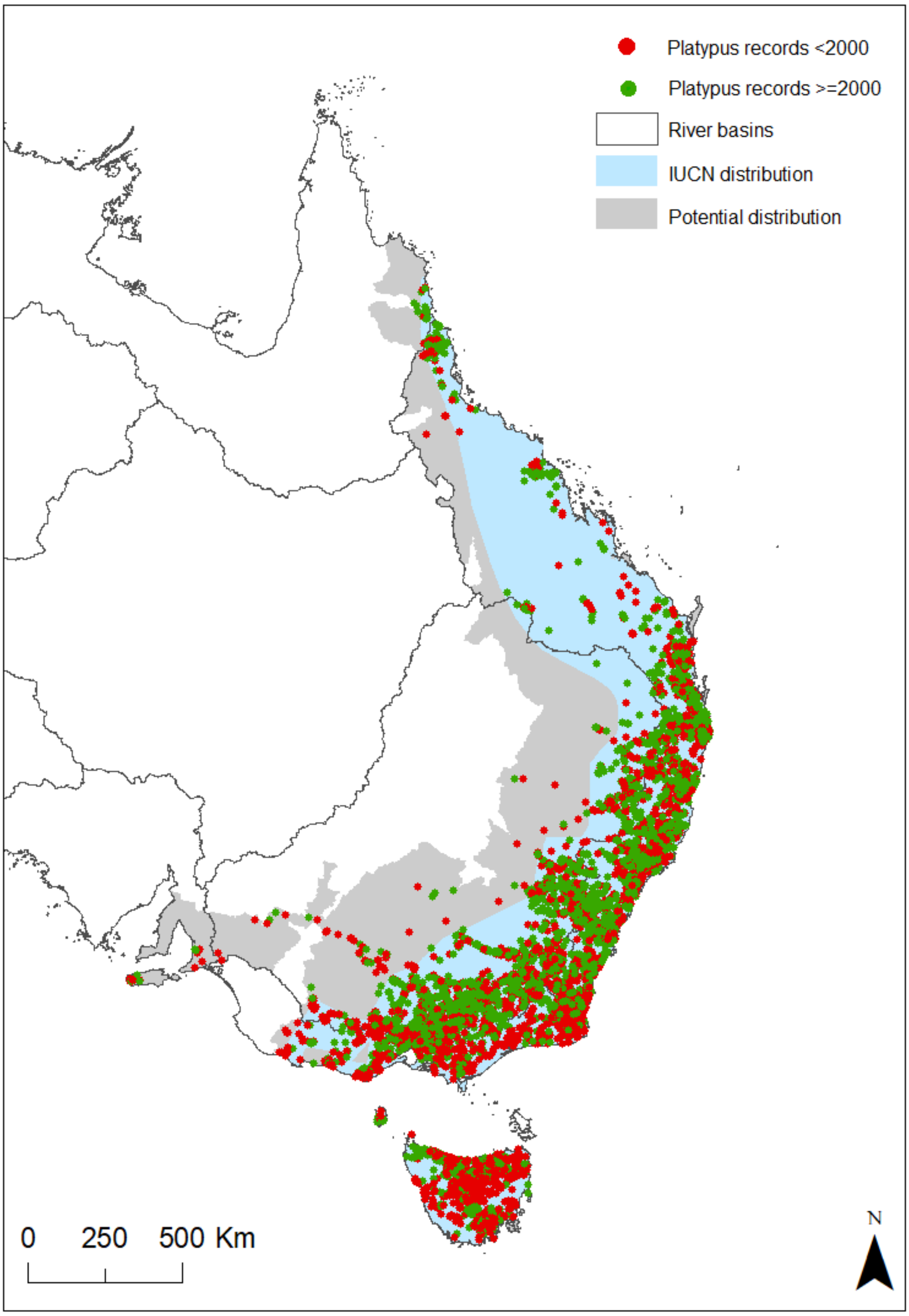

Figure 1. All reported sightings of platypuses (Atlas data bases, iNaturalist, museum records, Trove, platypusSPOT; 1885-2020; green since 2000, red prior to 2000), the current IUCN platypus distribution (blue shading) and sub-catchments (HydroBASIN Level 6 sub-catchment; Lehner et al. (2008)) which intersect the IUCN distribution or contain a platypus record.

Change in distribution

There are increasing reports of localized declines and extinctions of platypuses, but these are inconsistent across the range and difficult to quantify due to scarcity and uncertainty of empirical historical data, particularly estimates of abundances. To assess changes in the distribution of the platypus, we collated 14,484 distributional data points from the Atlas of living Australia[1], state atlas databases (ACT Wildlife Atlas Records[2]; BioNet Atlas of NSW Wildlife[3]; Tasmania Natural Values Atlas[4]; Victorian Biodiversity Atlas[5]; WildNet Queensland Wildlife Data[6]; Biological Databases of South Australia[7]), iNaturalist[8], museum records (Victorian Museum[9], Queensland Museum[10], The Australian Museum[11] and the Smithsonian National Museum of Natural History[12]), trove[13], and platypusSPOT[14]. We acknowledge that using citizen science data can lead to uncertainty and biases in estimating changes in a species' distribution. However, given the lack of widespread monitoring for platypuses, these records provide the only methods for assessing the species' distribution and changes to distribution. Additionally, given the unique morphology of platypuses and because they exclusively occupy rivers and streams, we consider these records valid, while acknowledging some potential false positives. To increase the reliability of records, where possible we ensured that all records used were valid or accepted within each database. Prior to analysis we also removed records with a coordinate uncertainty greater than 50 km. Additionally, there were 975 atlas records with an uncertain date, where a range between two dates was provided for when the platypus sighting may have occurred. For these records, we conservatively assigned them the date of the first possible sighting, to ensure we did not overestimate recent declines, acknowledging that this may also underestimate declines.

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[1] https://www.ala.org.au/ accessed 14/5/2020
[2] https://www.data.act.gov.au/Environment/ACT-Wildlife-Atlas-Records/e9ux-7djy accessed 14/5/2020
[3] http://www.bionet.nsw.gov.au/ 14/5/2020
[4] https://www.gbif.org/dataset/2985efd1-45b1-46de-b6db-0465d2834a5a accessed 14/5/2020
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[12] https://naturalhistory.si.edu/research/collections-national-museum-natural-history 28/8/2018
[13] https://trove.nla.gov.au/ accessed 28/8/2018
[14] https://platypusspot.org/ accessed 28/8/2018

Extent of Occurrence/Sub-catchments

We assessed changes at the sub-catchment level, given platypuses are restricted to rivers, and consider this the most reliable indicator of the Extent of Occurrence (EOO). Each distributional data point was assigned to a sub-catchment (HydroBASIN Level 7 sub-catchment; Lehner et al. (2008)). We assessed presence in a sub-catchment based on records, assuming no sightings was indicative of the absence of platypuses while acknowledging problems associated with false positives and false negatives. We quantified changes in platypus distribution using all records (1858-2020) and those over the last three generations (21 years; 2000-2020). We classify data into four time-periods: <2000, 2000-06, 2007-13, 2014-20 (Table 1 & Figure 3). To assess change, we calculated the number of sub-catchments that had their final year of platypus record within each time period.

Between 1858-2020, platypuses were recorded in a total of 279 sub-catchments (855,099 km^2; Table 1). Of these, 45 sub-catchments had their last recorded observation prior to 2000, representing a distribution loss of 107,577 km^2, prior to the last three generations (2000-2020). Since 2000, there were 45 sub-catchments which had their final platypus record in 2000-06 (113,219 km^2) and 21 between 2007-13 (46,140 km^2), (Table 1). This suggests that in the last three generations (2000-2020), platypuses have not been reported in 66 sub-catchments (159,358 km^2), representing a potential decline of 21.3% in the total area they have been reported. Since 1858, platypuses have declined from 31.2% of the total area where they have been reported. As platypuses are restricted to waterbodies, we estimated change in the length of river occupied by platypuses across this distribution. Rivers were defined to start at every pixel where the accumulated upstream catchment area exceeds 10 km^2, or where the long-term average natural discharge exceeds 100 liters per second (Grill et al. 2019). We assumed that if a platypus was recorded within a sub-catchment it could occupy all rivers within that sub-catchment. We calculated the length of rivers for each sub-catchment and compared changes since 2000 (Table 1), which indicate a decline of 21.1% in the length of rivers occupied by platypuses. Given increased fragmentation of rivers due to in-stream barriers, land-use change, and some evidence of localized declines in platypus numbers, the assumption that they occupy all rivers in a given sub-catchment with a record likely underestimates declines in length of occupied rivers.

Table 1. Number of platypus records, total sub-catchments (SC; HydroBASIN Level 7), river length, sub-catchments gained and lost, and declines in area (of sub-catchments, km^2), and river length for five time periods (1858-2020).

Time period	No. of records	Number of SCs with records	Cumulative SC with records	Total area (km^2)	River length (km)	SCs with first year of record	SCs with last year of record	Area of decline (km^2)	River length decline (km)
1858-1999	7075	241	241	773,109	179,050		45	107,557	24,104
2000-2006	3250	187	265	639,542	147,637	24	45	113,219	25,846
2007-2013	1743	139	271	493,363	116,648	6	21	46,140	10,812
2014-2020	2416	168	279	588,163	137,139	8			
1858-2020	14,484	279	279	855,099	197,902	38	111	266,936	60,763
2000-2020 (3 generations)	7,409	234		747,521	173,798	47	66	159,358	36,659

As changes in the distribution of platypuses were not consistent across the range, we calculated similar metrics for each of the major river basins and states that intersected sub-catchments where platypuses were recorded (

Table 2). Over the past 20 years (2000-2020), the Gulf of Carpentaria (40.5%) and Murray-Darling Basin have had the greatest decline in platypus records (27.9%). The largest declines were in QLD and NSW, with 29.6% and 28.5%, respectively.

Table 2. Percentage (%) decline in area (based on sub-catchments lost) and the decline in length of river occupied by platypuses since 2000, for each major river basin and state that intersects sub-catchments with platypus records.

Basin	**% area decline since 2000**	**% river length decline since 2000**
Gulf of Carpentaria	40.5	40.6
East Coast	18.3	18.3
Murray-Darling	27.9	27.7
Tasmania	5.2	5.6
South Australian Gulf	0	0
State	**% area decline since 2000**	**% river length decline since 2000**
QLD	29.6	29.4
NSW	28.5	28.1
ACT	0	0
VIC	5.1	5.3
TAS	5.2	5.6
SA	0	0

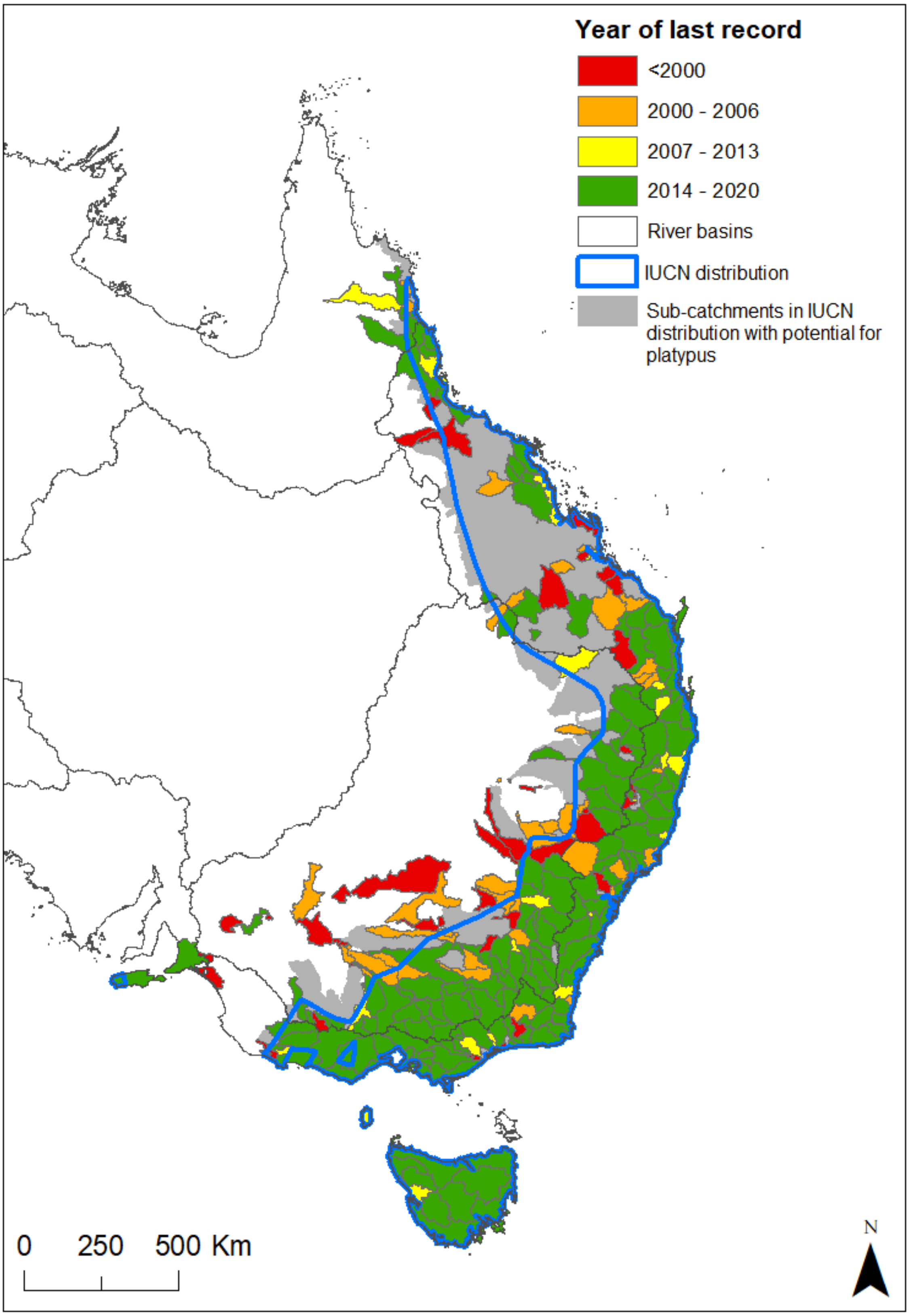

Figure 2. Last year of platypus record in each sub-catchment (HydroBASIN Level 7) across the distribution of platypus.

There are obvious differences in survey effort and the resulting number of records in each of the four time periods, which has the potential to impact the outcomes of this analysis. The 2000-2006 time-period had the highest number of records (3250; 45.5% of records between 2000-2020) and the highest number of sub-catchments with records. However, 45 sub-catchments lost record continuity, despite 4,159 records in the two later generational periods. Similarly, the lowest number of records was reported during the 2007-2013 time-period (1,743), yet 21 sub-catchments still lost record continuity, despite more records in the final year bracket (2,416). There were also increases in sub-catchments with platypus records, which we attribute to increased reporting rather than expansion in the distribution of the platypus. For this reason, although we report the number of sub-catchments gained, we do not calculate the net loss of sub-catchments, as this would infer these areas of gain counteract areas of decline.

Without widespread systematic surveys, currently lacking for this species, we cannot conclude the platypuses have disappeared from the sub-catchments where they are no longer reported by these citizen science data. However, atlas data shows increased reporting for water rats which occupy similar habitats to platypuses, echidnas which are their closest living relative, and even species that primarily inhabit rural areas, such as the spinifex hopping mouse (Hawke et al., 2020). Given increased public outreach and accessibility of platforms for reporting platypus observations in recent years, combined with new sub-catchments where platypuses are being reported, it is plausible that they may have disappeared from, or significantly declined in sub-catchments where they have not been reported since 2013.

The coarse scale of this analysis may underestimate area of declines as many of the sub-catchments have localized and often sparse records. To highlight this issue, we mapped the same 14,484 distributional data points but at a finer spatial resolution (HydroBASIN Level 8 sub-catchment). This highlights potential areas of more localised declines (Figure 3) across much of the section where platypuses have been sighted in 2014-2020 (dark green) in Figure 2. However, we consider the larger scale (Level 7 sub-catchments) more accurate for assessing changes, given finer spatial resolutions are more sensitive to lack of spatial record continuity.

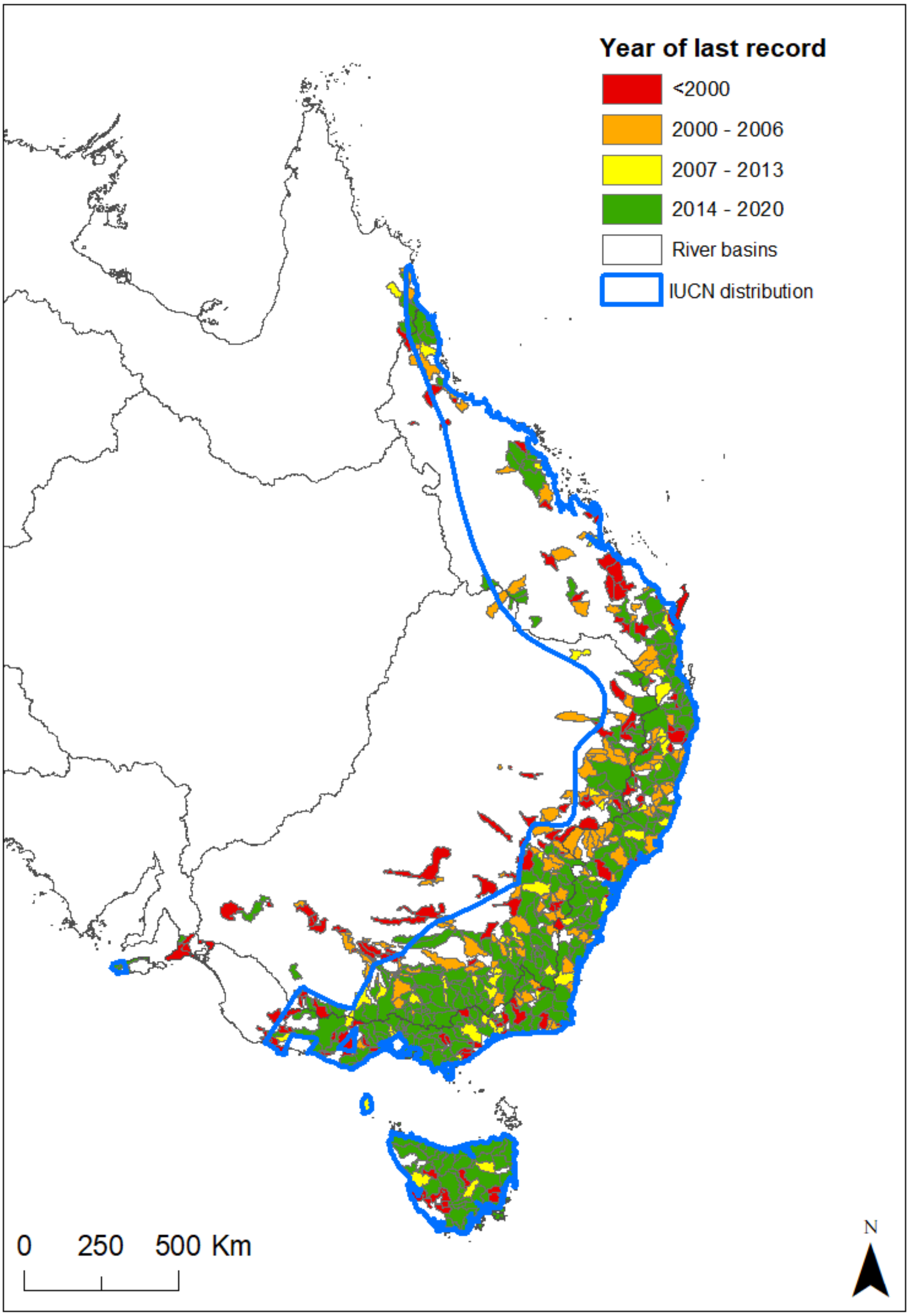

Figure 3. Last year of platypus record in each of the sub-catchments (HydroBASIN Level 8).

Another source of data for analysis of distribution is eDNA data. Some sub-catchments which had reported observations of platypuses, returned negative eDNA screening for platypuses, again supporting possibilities of more localized declines, although certainty of this varies with the intensity of eDNA sampling. For example, eDNA sampling failed to detect platypus from Enoggera Creek in Brisbane between 2016 - 2018, despite anecdotal sightings in 2005 from other areas within the same sub-catchment (Brunt et al., unpublished data). Recent eDNA surveys also indicate 16 sub-catchments where platypuses were not detected between 2018-2020 (Figure 4). None of these sub-catchments reported recent platypus observations. There are an additional 70 sub-catchments (green outline) where eDNA sampling has detected platypuses, all of which except two in central Queensland contain a platypus observation.

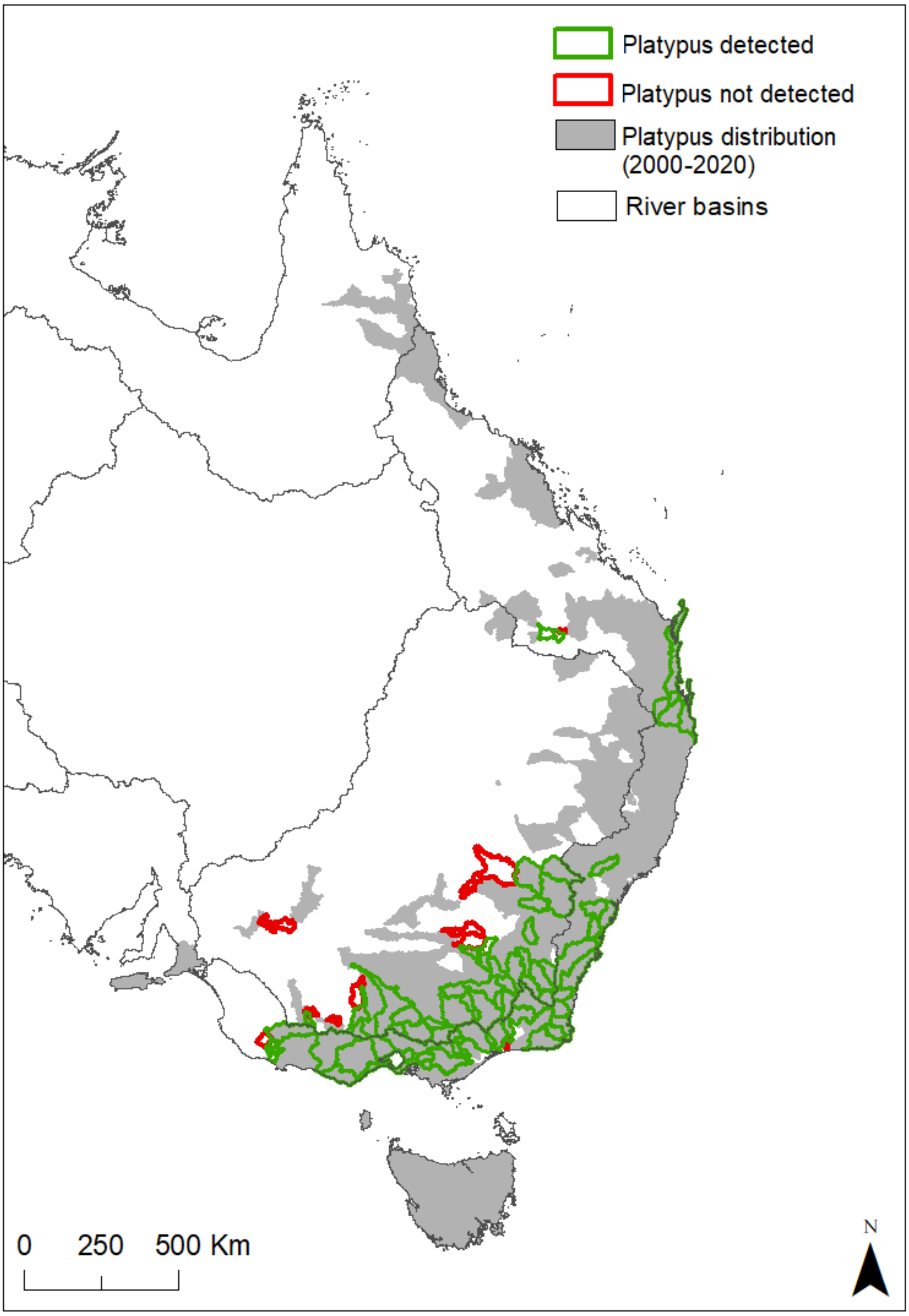

Figure 4. Sub-catchments (HydroBASIN Level 7) where platypus have not been detected (red outline) and where they have been detected (green outline) using eDNA sampling.

Area of occupancy

To determine the Area of Occupancy (AOO) and the decline in AOO, we assigned each distributional data point to a 2x2 km grid cell (Figure 2). We quantified AOO using all records (1858-2020) and those over the last three generations (21 years; 2000-2020). We classified data into the four time-periods: <2000, 2000-06, 2007-13, 2014-20, with the last three periods representing three platypus generations. We calculated the number of grid cells with platypus records and then calculated AOO using the equation: AOO = no. occupied cells × 4 km^2 (area of cell).

AOO derived from the intersect of platypus distributional data points and 2x2 km cells provides a lower bound of AOO which likely underestimates platypus distribution, given platypuses are likely to occur in areas where they have not been reported. For this reason, we also calculated the upper bound, based on the intersection of 2x2 km grid cells with creeks and rivers (Grill et al. 2019) within sub-catchments where platypuses were detected. This provided a likely upper estimate of the potential habitat for platypuses but is probably an overestimate.

Since 1858, there have been 6,677 grid cells with platypus records (lower bound; 26,708 km^2), (Table 3). Since 2000, there have been 4,110 grid cells with platypus records (16,440 km^2). Of these, there were a total 2,350 grid cells with records in the 2000-06 period (9,400 km^2), 890 with records in the 2007-13 period (3,560 km^2), and 1,397 cells in the last time period (2014-2020). The number of grid cells within the potential distribution of platypuses (upper bound) in the last three generations is estimated to be 94,656 2x2km grid cells (378,624km^2).

Table 3. The Area of occupancy for the platypus: lower bound (calculated as the number of 2x2 km grid cells which overlap platypus records) and upper bound calculated as the number of 2x2 km grid cells which overlap the potential distribution for platypus).

Time period	**2x2km cells with platypus record (area km^2)**
1858-1999	3,417 (13,668 km^2) – 96,217 (384,868 km^2)
2000-2006	2,350 (9,400 km^2) – 80,106 (320,424 km^2)
2007-2013	890 (3,560 km^2) – 63,174 (252,696 km^2)
2014-2020	1,397 (5,588 km^2) – 77,439 (309,756 km^2)
1858-2020	6,677 (26,708 km^2) – 107,118 (428,472km^2)
2000-2020	4,110 (16,440 km^2) – 94,656 (378,624km^2)

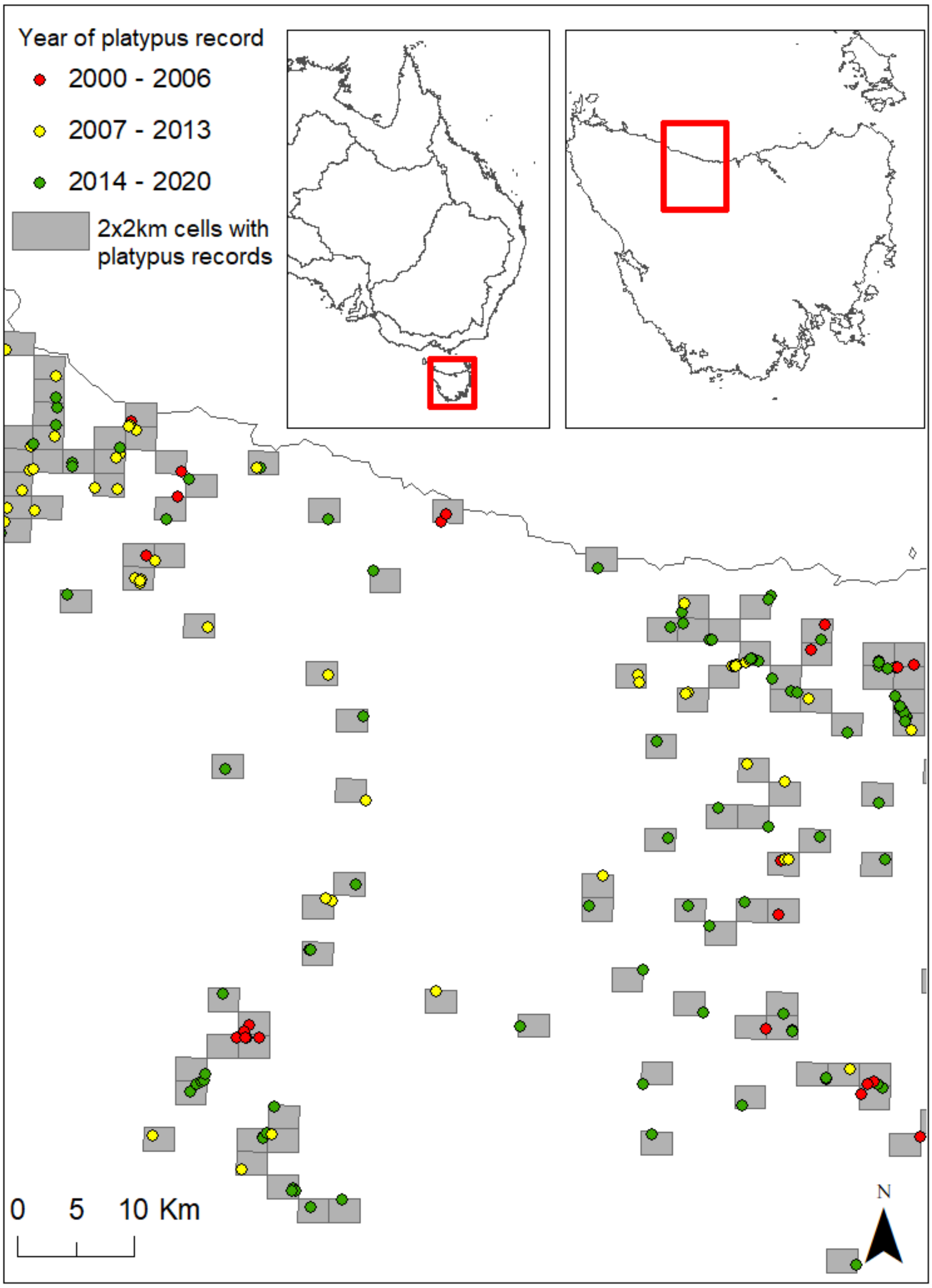

Figure 5. An inset of a region in north-western Tasmania showing 2x2 km grid cells with platypus records (red= 2000-06, yellow= 2007-13, green= 2014-20).

Habitat and ecology (see Appendix for additional information)

Systems

Terrestrial and freshwater

Generation length

Previous estimates of platypus generation length was 9-12 years (Woinarski et al. 2014) or 10 years (Furlan et al. 2012), calculated as the approximate mid-point between age at maturity (2 years; Grant et al. 2004) and maximum reported longevity in the wild (21 years; Grant 2004). An estimated generation length of 10 years was used for both IUCN red listing assessment (Woinarski and Burbidge 2016) as well as recently for listing in Victoria (*Flora and Fauna Guarantee Act 1998*).

For this assessment, we followed guidelines outlined by the IUCN and used the generation length calculator provided by IUCN (https://www.iucnredlist.org/resources/generation-length-calculator) which calculates the mean age at which a cohort of individuals produce offspring. We relied on estimated adult survival rates and fecundity based on data collected in the Shoalhaven River over 40 years (Bino et al. 2015, Grant 2004). We assumed the first year of platypus breeding to occur at two years of age (Grant et al. 2004)), with a fecundity rate of 0.47, an average annual adult survival of 0.83, and maximum longevity of 21 years in the wild (Bino et al. 2015). In Melbourne creeks, median adult longevity for males is estimated to be 6.3 years and 6.5 years for females (Serena et al. 2014).

Accordingly, this produced an estimated generation length of 7.31. Thus, this assessment examines declines over the past 21 year (i.e., three generations, 2000-2020).

Ecology

Platypuses are opportunistic predators, feeding predominately on a variety of benthic macroinvertebrates captured in pool and riffle habitats of streams and rivers. They forage between 8-16 hours each day and when not in the water are most often found resting in burrows made in the sides of riverbanks. They typically utilize 0.5-15 km of river, with males moving greater distances than females, particularly during the breeding season (Bino et al. 2019). Dispersing juveniles can move larger distances, particularly males, with reports of movements more than 40 km from their natal sites (Serena & Williams 2012).

The maximum life span recorded for platypus is 21 years in the wild and 25 years in captivity, with most generally surviving 6-15 years (Bino et al. 2019). They are seasonal breeders, breeding earlier in the year in lower latitudes: in NSW, breeding begins during August, with juveniles emerging from burrows between January and March compared to about two months later in Tasmania (Connolly & Obendorf 1998; Temple-Smith & Grant 2001). During courtship, female and male platypuses engage in courting behaviour where the male platypus holds the tail of the female with its bill, although sometimes this is better described as a "pounce and grab" with vigorous splashing prior to mating. The female then leads them through a series of slow twists and turns, followed by mating (Bino et al. 2019). Females will then construct or utilise an existing nesting burrow where they typically lay 1-3 eggs, hatching to dependent nestlings (usually 1 or 2). Nestlings are suckled in the burrow for 120-140 days in captivity (Hawkins & Battaglia 2009; Thomas et al. 2018), but probably for a shorter period in the wild (Grant et al. 2004).

Habitat

Platypuses are mainly aquatic, but occasionally move across land between water bodies and river catchments for dispersal (Furlan et al. 2013; Kolomyjec et al. 2009; Scott & Grant 1997). Platypuses prefer rivers and streams with pool and riffle sequences of 1-5 metres depth (Bryant 1993; Ellem et al. 1998; Grant 2004; Rohweder 1992), typically diving less than 3 metres (Bethge 2002). The complexity of bed substrate is also important in determining habitat quality, with a combination of gravel, pebbles, cobbles, and various sizes of larger rocks being important characteristics (Grant 2004; Rohweder 1992; Serena et al. 2001). Riparian vegetation is extremely important for platypuses, as it provides bank stability which is essential for the construction of burrows. Overhanging vegetation also provides in-stream organic material (Bryant 1993; Rohweder 1992; Serena et al. 2001). While all these factors are important for platypuses, they are found in a variety of habitats, many of which lack these characteristics, including degraded agricultural areas (Grant & Denny 1991; Rohweder & Baverstock 1999).

Platypuses make burrows in the sides of riverbanks and generally prefer vegetation-consolidated banks greater than 0.95 m in height (Brunt et al. 2018). Resting burrows are up to three metres in length, with the entrances mainly occurring above the surface of the water. Their nesting burrows, which are up to 30m long, are constructed by females over one or more breeding seasons to house dependent offspring until emergence (Burrell 1927).

Population

Historical numbers

Historical accounts of platypuses and numerical data from the fur trade suggest that platypuses were abundant at the end of the 19th century (

Table 4). In the Sydney markets, 9315 skins were sold between 1891-1899 (Hawke et al. 2019a). Sportsmen reportedly shot hundreds and sometimes thousands of platypuses, given that each garment or rug normally required more than 50 platypus skins. One furrier stated he had sold over 29,000 skins before the first world war (Hawke et al. 2019a).

Table 4. Quantitative historical records of platypus numbers (> 10) from digitized newspaper articles.

Year	Location	Number of platypus	Time/area	Event
1865	Shoalhaven River	16-18	"in a few hours"	Shooting
1881	Severn River	18	"on an expedition"	Shooting
1894	Murrumbidgee River	10	"in one day"	Spearing
1908	Yarra River	22	"in a day"	Capture
1933	Georges River	8-10 & 15	"at once"	Sighting
1934	Morwell River	13	"in two pools"	Sighting
1937	Snowy River	15-20	"at once"	Sighting
1954	Gloucester River	40	"at once"	Sighting

Historical qualitative literature also highlights how populations declined in response to the fur trade. Platypuses were described in records as highly abundant before the 1890s, then records suggest that they began to decline (

Table 5).

Table 5. Qualitative historical records of platypuses from digitized newspaper articles.

Year	State	Location	Observations
1865	QLD	Pike's Creek	"Platypus found in nearly every water hole"
1865	NSW	Yass River	"The platypus is also found in the banks of the stream in very large numbers"
1875	NSW	Campbell's River	"Immense numbers of platypus are found"
1879	NSW	Not reported	"Still common in most rivers and creeks of NSW and in some districts found in considerable numbers"
1890	NSW	Hay	"platypus are now nearly extinct"
1893	SA	Not reported	"formerly found in some of the few permanent streams of SA, has disappeared from this country, and in other exists in rapidly diminishing numbers"
1900	NSW	New England Region	"he has not seen in his district a wallaroo or platypus for fifteen years…where they once abounded in thousands"
1904	TAS	Not reported	"numbers are steadily decreasing, and if they continue to do so there is danger of extermination at no very distant date"
1905	NSW	Not reported	"They were numerous, and now they are only a few to be seen"
1909	NSW	Not reported	"but the platypus and the opossum are rapidly becoming extinct"
1910	VIC	Moorabool River	"becoming almost extinct, and is rarely met within the vicinity of large towns"
1910	NSW	Not reported	"these animals are being slaughtered every day and their skin sold". "these animals are very scare"
1912	NSW	Not reported	"still very scare, and in some districts quite extinct"
1923	QLD	Not reported	"the platypus is all but extinct"
1924	NSW	Not reported	"become almost extinct''
1926	NSW	Not reported	''once so common in some of our creeks and rivers, is also becoming a rarity''
1927	QLD	Not reported	"the platypus is nearly extinct"

1927	TAS	Not reported	"The platypus is not a disappearing species but an increasing one"
1928	VIC	Not reported	"they are far more numerous than they were ten years ago"
1929	QLD	Cooroy	"It has been many years since one of these animals has been seen locally"
1930	NSW	Wyong	"For the first time in 20 years a platypus has been caught"
1932	QLD	Eumundi	"This is the first one seen in the locality for a full decade, though at one time they were numerous"
1936	NSW	Macquarie River	"it is years since a platypus has ever been caught in any of the western rivers; it is a long time since a platypus has been seen on the Macquarie, although in days gone by they were to be found there in hundreds"
1937	NSW	Murrumbidgee River, Wagga	"This is the first platypus seen in the district for a great many years''
1940	VIC	Murray River, Echuca	"This must be one of the very few left in the country"

The fur trade likely had a significant impact on population numbers (Hawke et al. 2019; Hawke et al. 2020). Populations may have recovered in some areas after protection across the species' range in 1912 (e.g., 22 platypuses captured near Princes Bridge in 1908, 16 years after the species received legal protection in Victoria). At the time, there was also widespread land clearing in south eastern Australia (Walker et al. 1993), along with river regulation through the building of dams (Kingsford et al. 2011) and diversion of water. These synergistic human-driven threats in conjunction with low finite growth rate (λ=1.075 and λ=1.0047) (Bino et al. 2015; Fox et al. 2004, respectively), based on current estimates of juvenile recruitment (Grant et al. 2004; Serena et al. 2014) and survival (juvenile females $\Phi = 0.27 \pm 0.04$sd, juvenile males $\Phi = 0.13 \pm 0.02$sd) (Bino et al. 2015), continue to drive declines.

Contemporary numbers

Knowledge of platypus abundance across the distribution of the species is limited. They are generally considered common, but there is mounting evidence of localised declines and extinctions (Bino et al. 2019; Hawke et al. 2019a; Woinarski et al. 2014). There are few studies able to assess changes in populations trends, most of which have been undertaken at relatively localised scales, highlighting knowledge gaps across the range. We compiled available platypus literature (peer reviewed articles, reports, theses; 220 sources), resulting in 127 studies which undertook surveys or used platypus samples that could be assigned to a river region (Geoscience Australia 1997). Studies mainly focused on populations in Tasmania, the greater Melbourne area, and south eastern NSW (Figure 6).

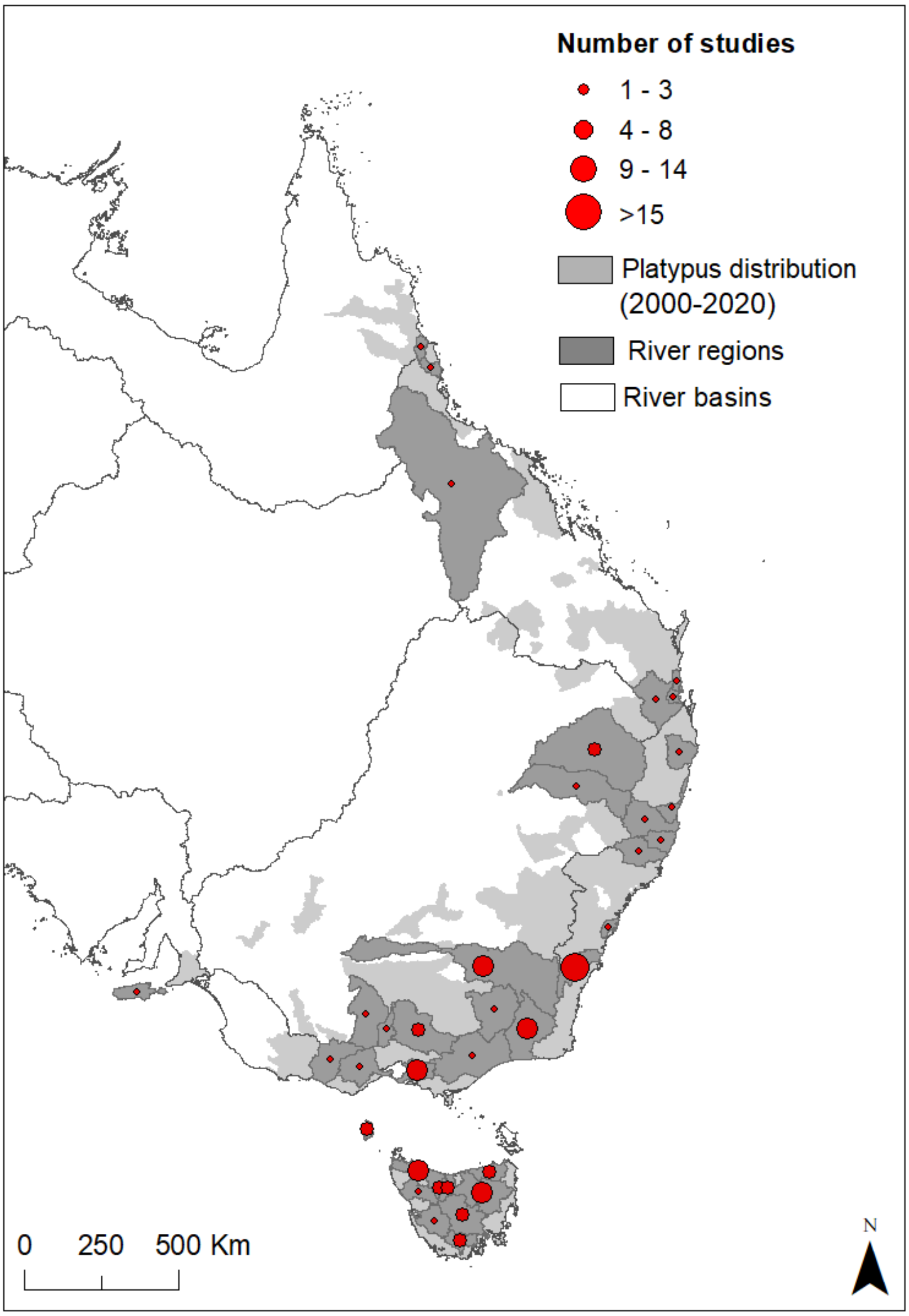

Figure 6. The distribution and number of studies (peer reviewed articles, reports, and theses) within river regions (dark grey) across the distribution of the platypus.

Some of these studies provided data for estimating catch per unit effort (catch per hour) or density, listed below (Table 6 and Table 7). The number of platypuses captured per hour during surveys ranged from 0.004-0.64 (mean = 0.19 ± 0.15sd). We report possible changes in capture rates over time (Figure 7), however, confounding impacts of river morphology, season, river flows, and unreported numbers of nets set likely also influence reported capture rates. Differences among states also reflects capture methods, as fyke nets have more commonly been deployed in Victorian and Tasmanian studies, compared to studies conducted in NSW, which have most often used gill nets to sample larger water bodies.

Table 6. The year of study, river, and number of platypuses captured per hour of survey from available platypus literature.

Reference	Year of study	State	River	CPH mesh	CPH fyke	CPH combined
(Grant et al. 1992)	1988-89, 1991	NSW	Thredbo River	0.12		
(Serena 1994)	1989-92	VIC	Badger Creek		0.05	
(Goldney 1995)	1991-93	NSW	Thredbo River			0.065
(Connolly & Obendorf 1998)	1994	TAS	Brumbys Creek	0.08		
			Liffey River	0.14		
			Emu River	0.23		
			Mersey River	0.14		
			Weegena farm dams	0.25		
(Serena et al. 1998)	1995-97	VIC	Diamond Creek		0.05[a]	
			Mullum Mullum Creek		0.20[a]	
(Lunney et al. 2004)	1996	NSW	Kalang River	0.23		
			Bellinger River	0.22		
(Bethge et al. 2001)	1997-1998	TAS	Tasmania			0.23
(Bethge 2002)	1997-98	TAS	Plenty River	0.23	0.07	
(Bethge 2002)	1998-2000	TAS	Lake Lea	0.13	0.03	

Reference	Year of study	State	River	CPH mesh	CPH fyke	CPH combined
(McLachlan-Troup 2007)	1998-2001	NSW	Kangaroo River and Brodgers Creek	0.30		
(Williams & Serena 2000)	2000	VIC	Coliban River		0.42[a]	
(Williams & Serena 2002)	2002	VIC	Loddon River		0.16[a]	
Grant, T. R. (unpublished)	2002	NSW	Wingecarribee River	0.42		
			Nepean River	0.15		
(Williams 2004)	2003	VIC	Mount Emu Creek		0.38[a]	
Grant, T. R. (unpublished)	2006	NSW	Wingecarribee River	0.64		
			Nepean River	0.12		
(Serena & Williams 2008)	2008	VIC	Wentworth River/Pheasant Creek		0.20[a]	
			Valencia Creek		0.10[a]	
			Mount Skene Creek/Barkly River		0.20[a]	
			Aberfeldy River/Donnelly Creek		0.004[a]	
(Gust & Griffiths 2011)	2008-09	TAS	Tasmania			0.02
(Connolly et al. 2016)	2009-10	NSW	Murrumbidgee Catchment	0.05		
(Bino et al. 2015)	1973-2014	NSW	Shoalhaven River	0.41		

<table>
<tr><th>Reference</th><th>Year of study</th><th>State</th><th>River</th><th>CPH mesh</th><th>CPH fyke</th><th>CPH combined</th></tr>
<tr><td rowspan="7">(Hawke et al. 2021a)</td><td rowspan="5">2016-17</td><td rowspan="5">NSW</td><td>Snowy River</td><td>0.31</td><td></td><td></td></tr>
<tr><td>Thredbo River</td><td></td><td></td><td>0.16</td></tr>
<tr><td>Eucumbene River</td><td></td><td>0.23</td><td></td></tr>
<tr><td>Tenterfield Creek</td><td></td><td></td><td>0.23</td></tr>
<tr><td>Severn River</td><td></td><td></td><td>0.25</td></tr>
<tr><td rowspan="2">2018</td><td rowspan="2">VIC</td><td>Mitta Mitta River</td><td></td><td></td><td>0.05</td></tr>
<tr><td>Ovens River</td><td></td><td></td><td>0.08</td></tr>
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[a]Estimated based on an assumed 12-hour fyke net trapping night

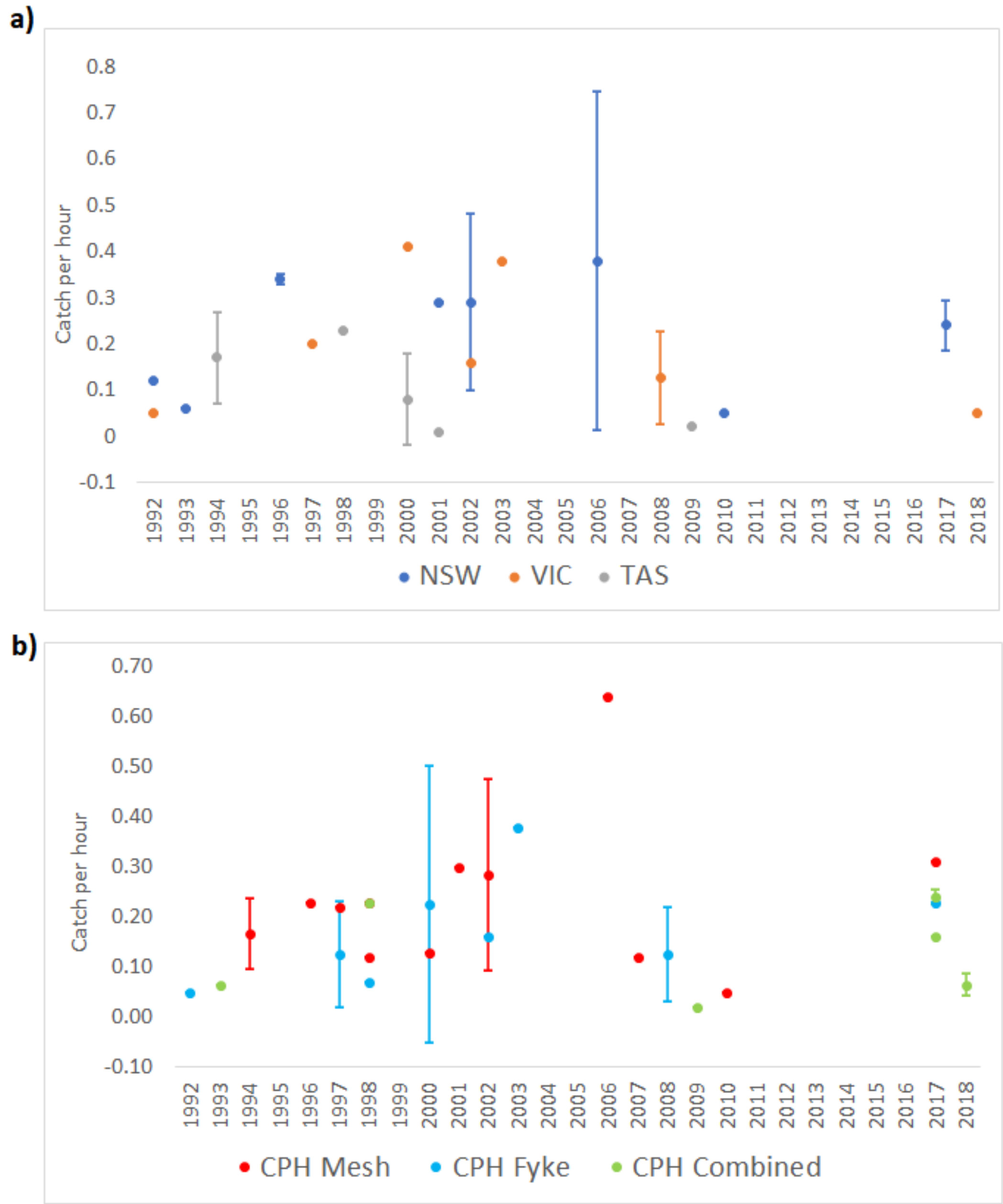

Figure 7. The average catch per hour (± SD) of platypuses across years (1992-2018) for a) different states: NSW (blue), VIC (orange) and Tasmania (grey) and b) different net type: mesh nets (red), fyke nets (blue), and combined nets (green).

Density estimates of platypuses range from 1.3/km to 19.3/km (mid-point average 5.1/km ± 3.8sd, average of lower estimates = 3.5/km ± 2.8sd, average of upper estimates = 6.3/km ± 5.6sd; Table 7). Although derived from studies with varying survey effort, from variable habitats and having differing surveys objectives (e.g., targeting prime platypus habitat vs. systematic surveys across a region), estimates provide indicative recent ranges of platypus densities.

Table 7. The year of study, river, and density estimate of platypuses captured/km based on available platypus literature.

Reference	Year of study	State	River	Numbers/km	Capture effort
(Grant et al. 1992)	1988-89, 1991	NSW	Thredbo River	10.8	293 net hours
(Bino et al. 2015; Serena & Grant 2017)	1973-2014	NSW	Shoalhaven River	2.8 -19.3 (12.4)	5,600 net hours
(Serena 1994)	1989-92	VIC	Badger Creek	1.3-2.1	67 net nights
(Goldney 1995)	1991-93	NSW	Thredbo River	2.5	1,289 mesh net hours, 199 fyke net nights
(Gardner & Serena 1995)	1992	VIC	Watts River	1.3	44 net nights
	1993			1.25	
			Badger Creek	1.75	
(Koch 2001)		TAS	South Esk River	3-7	
(Serena & Williams 1997)	1996	SA	Breakneck River	3.6	4 sites
	1996		Rocky River	2.0	13 sites
	1997		Rocky River	1.3	
(Hawke et al. 2021a)	2016-17	NSW	Snowy River	7.4-12.6	42 trapping nights
			Thredbo River	3.4-6.3	17 trapping nights
			Eucumbene River	9.3-16.7	8 trapping nights
	2018	VIC	Mitta Mitta River	1.7-6.0	37 trapping nights
			Ovens River	4.7-8.4	25 trapping nights
(Williams & Serena 2019)	2019	VIC	Campbells Creek	1.4	1 trapping night

Population trends

We examined trends in annual number of platypus records from all collated platypus occurrence records for each sub-catchment over the past 21 years (2000-2020, 7,409 records; Figure 8; Figure 9). Given increased surveys and citizen science initiatives, particularly over the past decade, we predicted positive trends in number of platypus observations across much of the species' range. Consequently, we postulate that negative trends may imply lower platypus numbers but also areas with a weak (marginally significant) negative trend, may also be indicative of declines.

In each of the sub catchments with platypus records since 2000 (n=234), we tested for differences in annual records in each of the three 7-year time periods (2000-06, 2007-13, 2014-20) using a Generalised Linear Model with a Poisson distribution.

Between the first (2000-06) and second (2007-13) time periods, 51 sub-catchments (22%) had significantly ($P \leq 0.05$) higher number of platypus records in the latter period while 12 (5%) had a lower number of records (Figure 10). An additional six (24%) and three (6%) sub-catchments had marginally significant ($0.05 > P \leq 0.10$) higher and lower number records in the latter period, respectively (Figure 8). In terms of proportion of habitat (individuals), as inferred from modelled platypus distribution (see 'Estimated current population size' section and Figure 14), significant increases were recorded in 36% of the species' habitat and significant decreases in 10%.

Between the first (2000-06) and third (2014-20) time periods, 46 (20%) had significantly higher number of records in the latter period while 19 (8%) had lower numbers. An additional 11 (24%) and one (9%) had marginally significant higher and lower numbers in the latter period, respectively. In terms of proportion of habitat (individuals), increases were recorded in 26% of the species' habitat and decreases in 10%.

Between the second (2007-13) and third (2014-2020) time periods, 13 (6%) had significantly higher number of records in the latter period while 29 (12%) had lower numbers. An additional one (6%) and seven (15%) had marginally significant higher and lower numbers in the latter period, respectively. In terms of proportion of habitat (individuals), increases were recorded in 8% of the species' habitat and decreases in 22%.

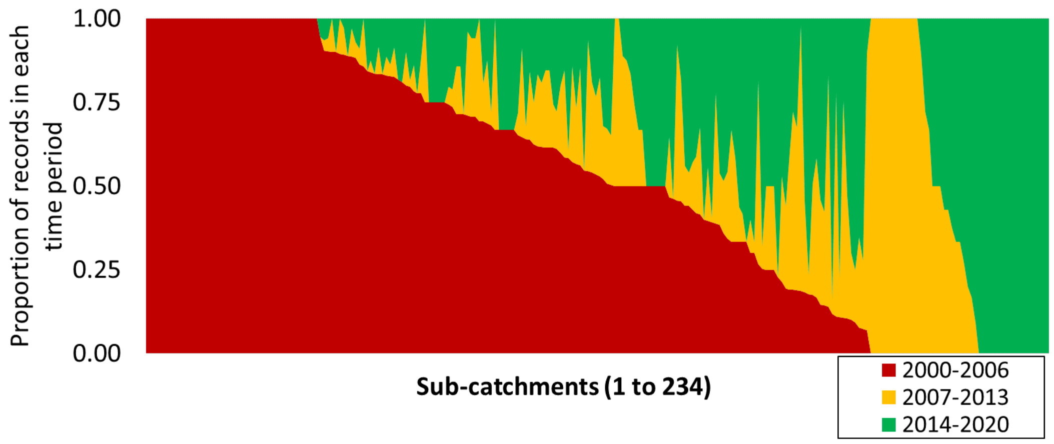

Figure 8 Proportion of platypus records since 2000 (n=7,409) by decade in each of the 234 sub-catchments

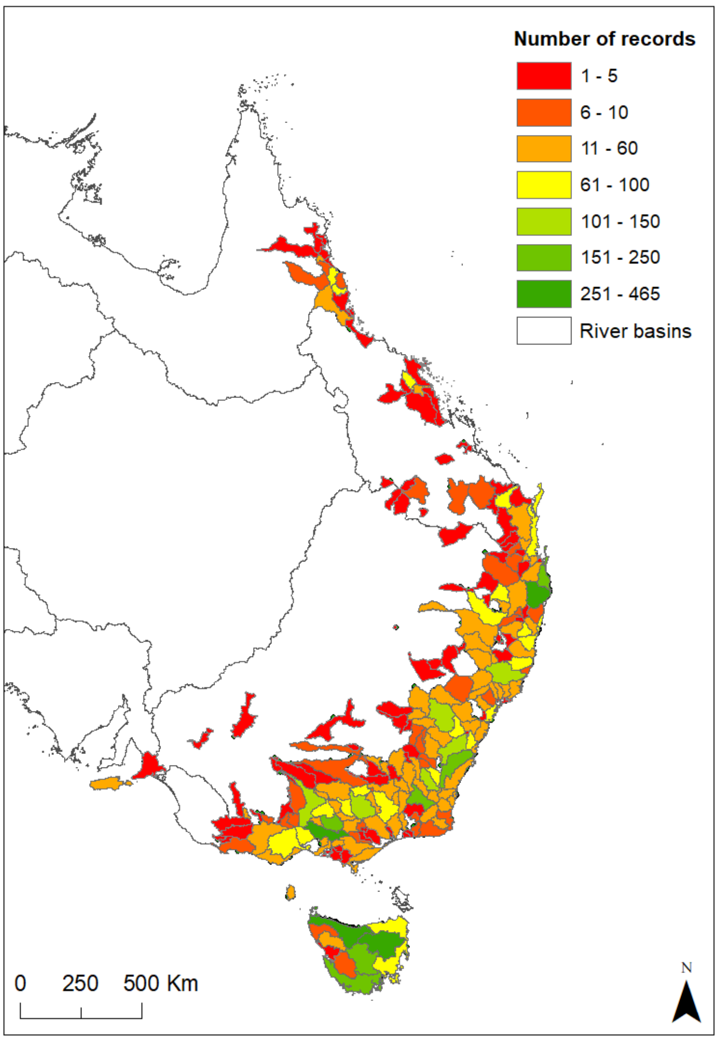

Figure 9 Total number of platypus records between 2000 and 2020 in each sub catchment collated from multiple sources.

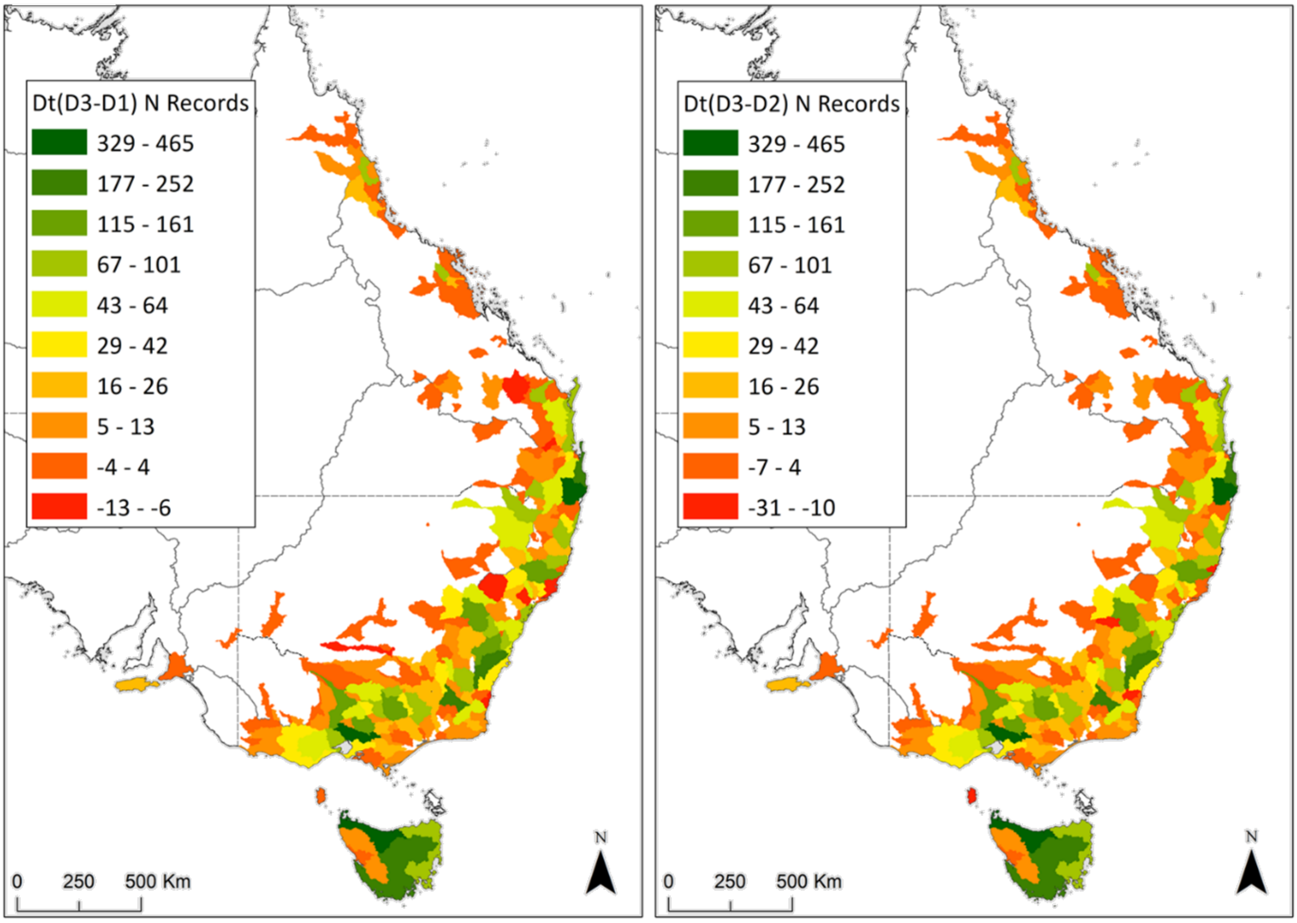

Figure 10 Change (Dt) in the number of records between (left) 2000-06 (D1) and 2014-20 (D3) and (right) 2007-2013 (D2) and 2014-2020 (D3).

Case study: Greater Melbourne region

Since 1995, platypus surveys have been undertaken across five river basins in the greater Melbourne region (Dandenong, Yarra (Lower Yarra and Upper Yarra), Maribyrnong, Werribee, and Western Port; Figure 11) by the Australian Platypus Conservancy (APC) (1995-2007) and Cesar (2007 – 2019) across 33 sites varying in survey efforts (Appendix 2). During this time (~25 years), rapid urban growth has significantly altered land use cover (Rahnama et al., 2020; Taskforce, 2010) also impacting water quality (Sharley et al., 2017; Shi et al., 2019) and flow variability (Walsh and Webb, 2016). High urbanisation rates are expected to continue (Melbourne Water, 2018). Significant natural environmental fluctuations have also occurred over this period. Importantly, during the Millennium Drought (2001-2009), number of cease to flow days considerably increased which was strongly associated with reduced platypus captures during surveys, with more pronounced effects when considering longer time periods of 10 years (Griffiths et al. 2019).

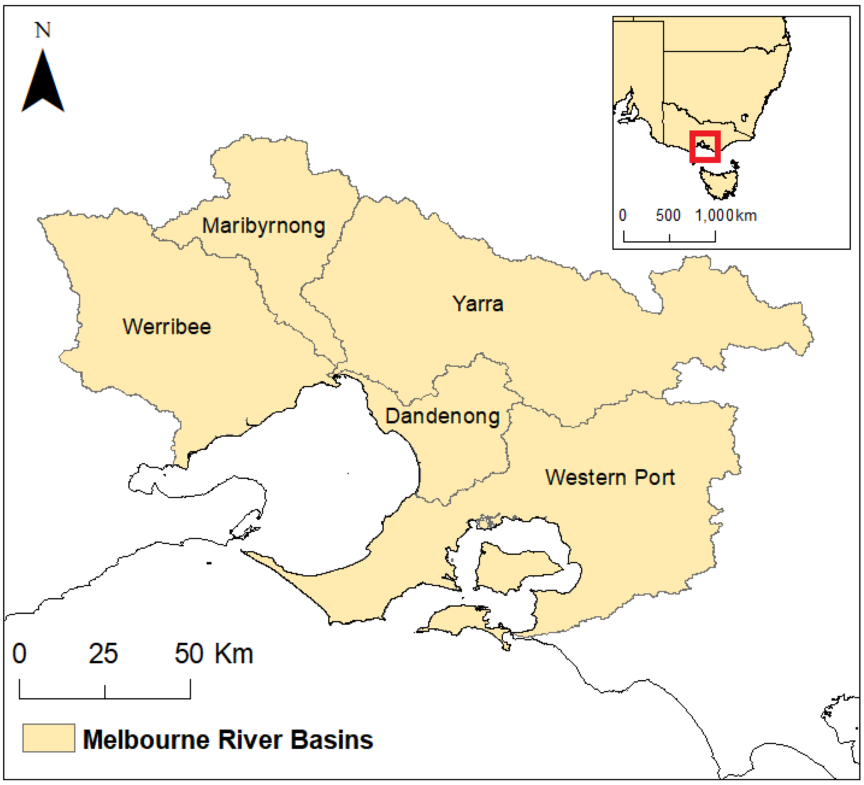

Figure 11. Location of river basins in the greater Melbourne area where platypus surveys have been undertaken, 1995-2019.

To evaluate trends in platypus numbers we modelled platypus captures using a generalized linear mixed effect model using the 'glmmTMB' package (Brooks et al., 2017) within the R environment (R Development Core Team 2020). We considered varying and non-linear trends in each catchment by incorporating an interaction term between a second-order polynomial term of year and catchment. We included sites within catchments as a random effect to account for fine scale variation in habitat as well as the number of trapping nights in each site as an offset term of survey effort. As variation in survey design and site selection, beyond considered survey effort, may exist between the two organisations (Serena and Williams, 2019), we considered the organisation undertaking the surveys as an explanatory factor. However, due to non-overlapping survey periods at opposing ends of an extended drought, it is difficult to differentiate the potential influence of organisation undertaking the surveys from significant environmental changes (e.g., Millennium Drought and urban expansion) on CPUE. Further analysis is required to elucidate the causes of declining CPUE over time.

Model results suggested significant non-linear trends in platypus numbers, which varied across catchments but with overall declines coinciding with the Millennium Drought and recovery in recent years. Between 1995-2004 and 2010-2019 periods, average declines were predicted in the Lower Yarra (54%, 95%CI: 34% - 65%) and Werribee (65%, 95%CI: 59% - 68%) catchments, and to a lesser extent in the Western Port (26%, 95%CI: 9% - 43%) and Dandenong (18%, 95%CI: 4% - 40%) catchments while net increased were predicted in the Maribyrnong (+83%, 95%CI: +46% - + 137%) and Upper Yarra (+92, 95%CI:+82% - +102%) (Figure 12; Figure 13; Appendix 2).

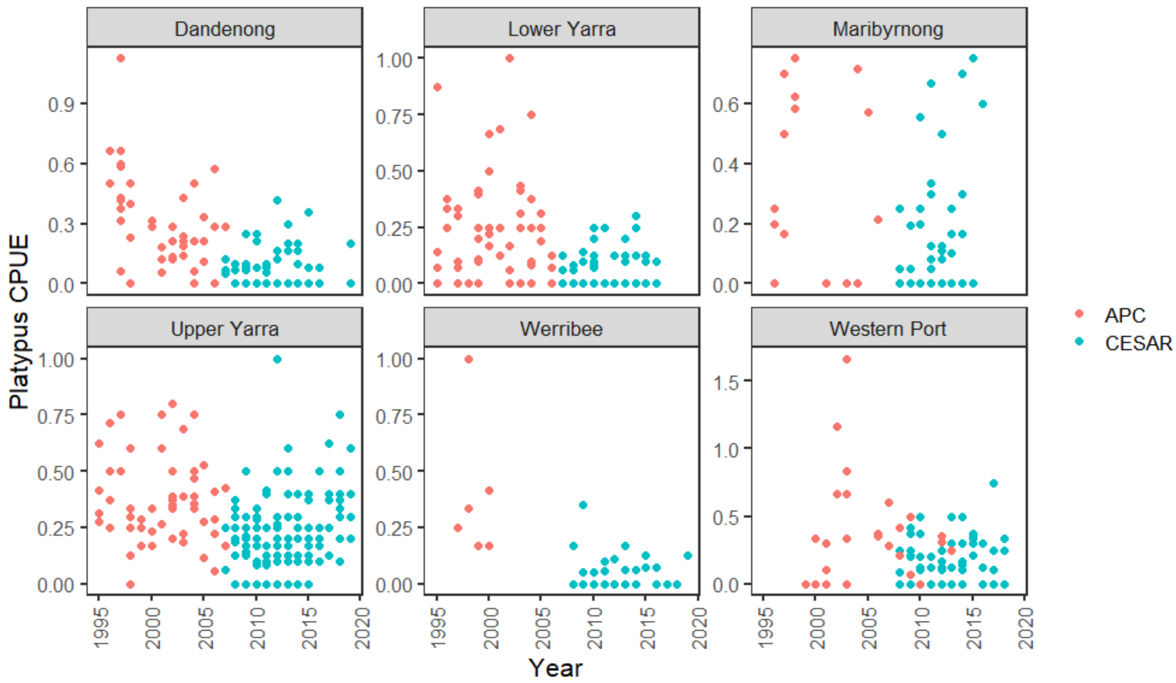

Figure 12. Platypus surveys (catch per unit effort (CPUE)) across the six river basins in the greater Melbourne region between 1995-2019, coloured by organisation conducting the surveys (Australian Platypus Conservancy - red, Cesar - blue). See Appendix 2 for site plots.

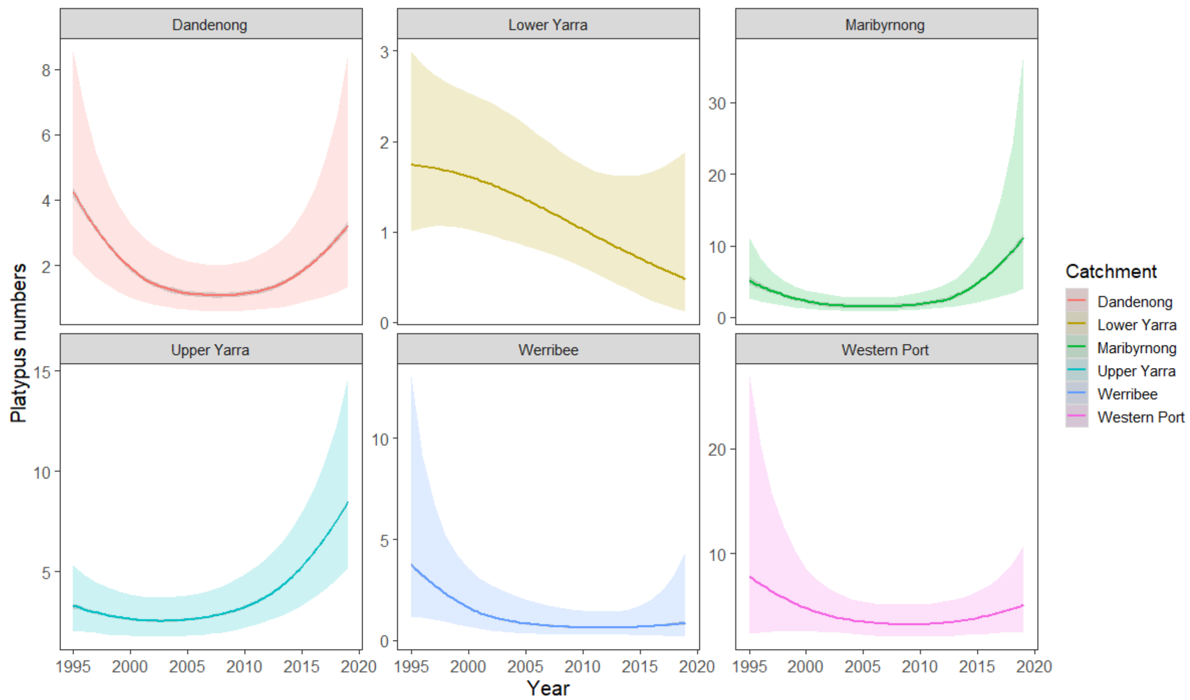

Figure 13 Predicted platypus captures using generalized linear mixed model (see appendix 2 for further details).

An assessment submitted to the Victorian Scientific Advisory Committee[1], in support of the platypus' nomination as a threated species, examined trapping and eDNA surveys as well as wildlife atlas data (Cesar Australia, unpublished data), estimated a 50% decline in length of platypus occupancy for waterways in the Melbourne catchments (Table 8). Due to limitations of historical data, the assessment includes some judicious assumptions relating to the platypus' previous distribution in each of the areas and may overestimate declines (Serena, M. per comm).

Table 8. Length (km) of waterways in greater Melbourne catchments estimated to be occupied by platypus (Cesar Australia, unpublished data)

	Historical	Current	% decline
Werribee	253	63	75%
Maribyrnong	295	126	57%
Yarra	962	597	38%
Dandenong	96	8	92%
Western Port	359	195	46%
Total	1965	989	50%

[1] https://www.environment.vic.gov.au/__data/assets/pdf_file/0030/484086/01-Platypus-PRR-FinalSign-1.pdf

Estimated current population size

Given existing uncertainties, accurate estimates of number of mature platypuses across their range are difficult to calculate. We attempt to derive ranges of estimated number of platypuses using a species' distribution modelling approach, modelling association between platypus observations and habitat metrics, and then extrapolating platypus probability of occurrence across the species' range using density estimates (Table 7).

We collated 14,484 platypus observations from the Atlas of living Australia[3], state atlas databases (ACT Wildlife Atlas Records[4]; BioNet Atlas of NSW Wildlife[3]; Tasmania Natural Values Atlas[4]; Victorian Biodiversity Atlas[5]; WildNet Queensland Wildlife Data[6]; Biological Databases of South Australia[7]), iNaturalist[8], museum records (Victorian Museum[9], Queensland Museum[10], The Australian Museum[11] and the Smithsonian National Museum of Natural History[12]), Trove[13], and platypusSPOT[14]. Records without a year of sighting were removed from the analysis. To increase model accuracy, we excluded platypus records with a spatial accuracy less precise than 50 km and then spatially aligned all remaining records to the nearest stream (Stein et al. 2014).

We then modelled habitat suitability for platypuses (Figure 14), using the Biodiversity & Climate Change Virtual Lab and the Maximum Entropy Species Distribution Modelling approach (Phillips & Dudik 2008). We considered two temporal spans, the first considering all available records (1885-2020; 14,484 records) and the second, only those over a 21-year assessment period, from 2000-2020 (7,409 records). For each time period, we randomly generated an equal number of background pseudo-absences (Barbet-Massin et al. 2012) across

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[1] https://www.ala.org.au/
[2] https://www.data.act.gov.au/Environment/ACT-Wildlife-Atlas-Records/e9ux-7djy
[3] http://www.bionet.nsw.gov.au/
[4] https://www.gbif.org/dataset/2985efd1-45b1-46de-b6db-0465d2834a5a
[5] https://www.environment.vic.gov.au/biodiversity/victorian-biodiversity-atlas
[6] https://www.qld.gov.au/environment/plants-animals/species-information/wildnet
[7] https://www.environment.sa.gov.au/topics/Science/Information_data/Biological_databases_of_South_Australia
[8] https://www.inaturalist.org/
[9] https://collections.museumsvictoria.com.au/
[10] https://www.qm.qld.gov.au/collections
[11] https://australian.museum/
[12] https://naturalhistory.si.edu/research/collections-national-museum-natural-history
[13] https://www.gbif.org/dataset/2985efd1-45b1-46de-b6db-0465d2834a5a
[14] https://platypusspot.org/

an area defined by minimum convex polygon of all platypus records. We considered eight explanatory variables, biologically relevant to platypus and based on the stream and nested catchment framework for Australia (Stein et al. 2014). These included four environmental variables of contemporary climate (Annual Mean Temperature, Max Temperature of Warmest Moth, Annual Precipitation, Precipitation of Driest Quarter; 1921-1995 (Xu & Hutchinson 2013), two terrain variables (stream order and maximum segment elevation) (Hutchinson 2008) two current woodland and forest cover variables (Australian Government 2006), percentage of urban and modified land (not for conservation) and the river disturbance index (Stein et al. 2014). The rationale for including temperature was based on the species' intolerance to temperatures above 30°C (Robinson 1954) and for precipitation on its dependence on freshwater habitats (Bino et al. 2019). We included terrain variables, given the species' habitat preference for mid and lower river reaches and waterways (Koch et al. 2006; Macgregor et al. 2015; Rohweder & Baverstock 1999; Serena et al. 1998; Serena et al. 2001; Turnbull 1998). We also incorporated catchment-scale native tree cover as a surrogate for erosion and sedimentation as well as for riparian cover which provides shelter, burrows and organic matter for prey while cleared areas increase erosion and sedimentation of rivers (Bryant 1993; Ellem et al. 1998; Rohweder 1992). We also acknowledge that there are some platypus populations which occur in streams and rivers which flow through agricultural land (Lunney et al. 1998), but consider vegetation clearing to be an important contributor to the synergistic threats facing platypuses.

Statistical models were carried out at a 250m grid cell resolution. Predictive performance of the platypus distribution model was evaluated using the area under the receiver operating characteristic curve (AUC) and Cohen's Kappa using a ten-fold cross-validation analysis (Hijmans 2012; Fielding & Bell 1997; Stockwell & others 1992). To maximise model accuracy, we examined the sensitivity-specificity of models and identified the best probability threshold value, which was P=0.13 when considering all observations and P=0.09 when considering observations since 2000 (Appendix 3).

To derive estimates of platypus numbers we linearly scaled derived probability of occurrence (0-1) with observed minimum (3.5), mid-point (5.1) and maximum (6.3) platypus numbers/km (Table 7). Explicitly, in areas of high environmental suitability, where the relative likelihood of occurrence predicted by the Maxent models was P=1.0, platypus densities ranged between 3.5 (minimum) to 6.3 (maximum). Lower probabilities of occurrence linearly scaled down density estimates.

When using all available occurrence records, the predicted number of total platypuses across the distribution ranged between 194,562 to 350,212. When using only occurrence records since 2000, predicted number of total platypuses across the distribution ranged between 186, 847 to 336,325. Estimates of platypus numbers likely omit large areas in the species' northern extent as they are deficient in observations which lower predicted occurrence. Estimates may also be lower as these models consider pooled observations over extended periods and disregard population dynamics and trends in response to threatening processes and stochastic events such as droughts (see next section).

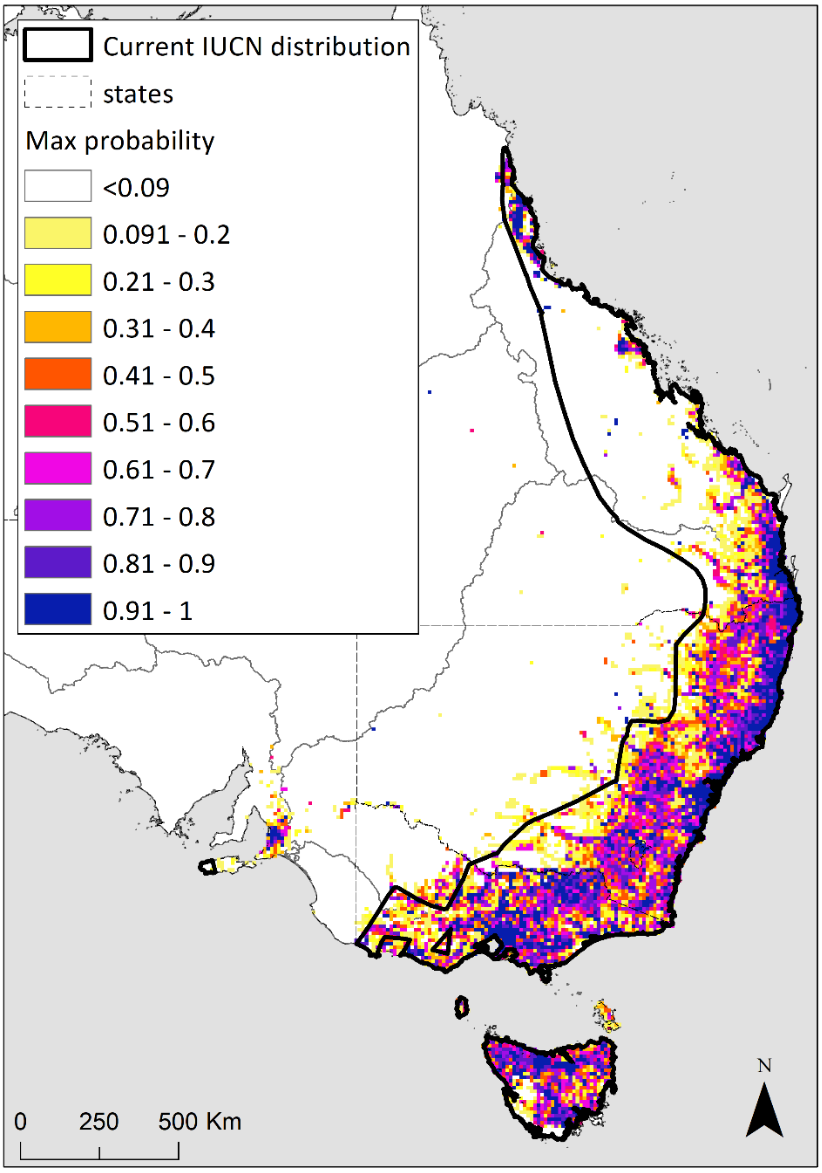


Figure 14. Probability of occurrence in eastern-Australia based on the species distribution model for platypuses using records since 2000. For illustration purposes, the map depicts maximum probability of occurrence at a scale of 1km derived from prediction at a scale of 250m.

Extinction probability and viability models

This section aims to exemplify the synergistic impacts of threatening processes and possible declines in platypus populations in recent decades. Explicitly, we examine the combined impacts of fragmentation, lowered habitat quality, and increasing frequencies of severe droughts on the viability of localised platypus populations and the entire meta-population.

There are several approaches to modelling population viability, tailored for specific needs and scales, broadly grouped to Individual Based Models and discrete population-based model (Lacy 2019). We use the RAMAS GIS (Akçakaya & Root 2013) to construct a metapopulation dynamic model of platypus populations. Our decision was based on the capacity of RAMAS GIS to consider the spatial structure of many different populations, while integrating the effects of habitat fragmentation and other threatening processes at a continental scale.

Given platypus are obligate freshwater animals, almost exclusively confined to rivers and waterways (Bino et al., 2019), we used river catchments as the scale for analysis. We used the HydroBASINS framework (Lehner & Grill 2013), which divided basins into sub-basins at every location where two river branches met, each with an upstream area of at least 100 km^2, continuing further with subsequent subdivisions (Verdin & Verdin 1999). We used the seventh sub-basin level, producing 775 potential areas where platypuses occur (hereafter population units), overlapping with the platypus suitability map, encompassing an average of 156km ± 180sd (range 0.02 – 1,442 km) of major rivers and 1,105 km ± 1394 sd (range 0.06 – 9,178 km) of minor rivers, with an average land area of 2,460 km^2 ± 2,663 sd. Given the computational limitations of the software we did not used the eight sub-basin level which would have produced over 6,000 populations units with an average land area of 1,231 km^2 ± 985 sd.

To quantify connectivity between platypus population units, we used the Australia Hydrologic Geo-Fabric (AHGF) stream network, based on the GEODATA Nine Second Digital Elevation Model (DEM-9S) Version 3 (Hutchinson 2008). The built-in Network Analyst in ArcMap (ESRI, 2010) was the analytical framework for the river network, providing estimates of distances along the stream network and between platypus population units. We used the distance between populations along the stream network to calculate emigration potential, where annual stage-dependant dispersal rate was P=0.25 for individuals (male juvenile P=0.12, female juvenile P=0.04, male adult P=0.06, female adult P=0.04 (Bino et al. 2015; Fox et al. 2004). We explored sensitivity of dispersal estimates by assessing variation of ±20% in dispersal rates. Adjacent population units along the river network were assigned a zero distance, recognising their probable connectivity, with equal probabilities assigned for up or downstream dispersal (Bino et al. 2019). For non-adjacent population units along the river network, emigration potential (A) was calculated using a dispersal distance function based on the assumption that average dispersal was 2 km (Bino et al. 2019) with some extreme instances exceeding 40 km (Serena and Williams 2012):

$$A = 0.25 \cdot \left(\frac{e^{\frac{-x}{10}}}{\sum_i^N e^{\frac{-x}{10}}} \right)$$

where x was the distance [km] between population units (N) along the stream network (Figure 15).

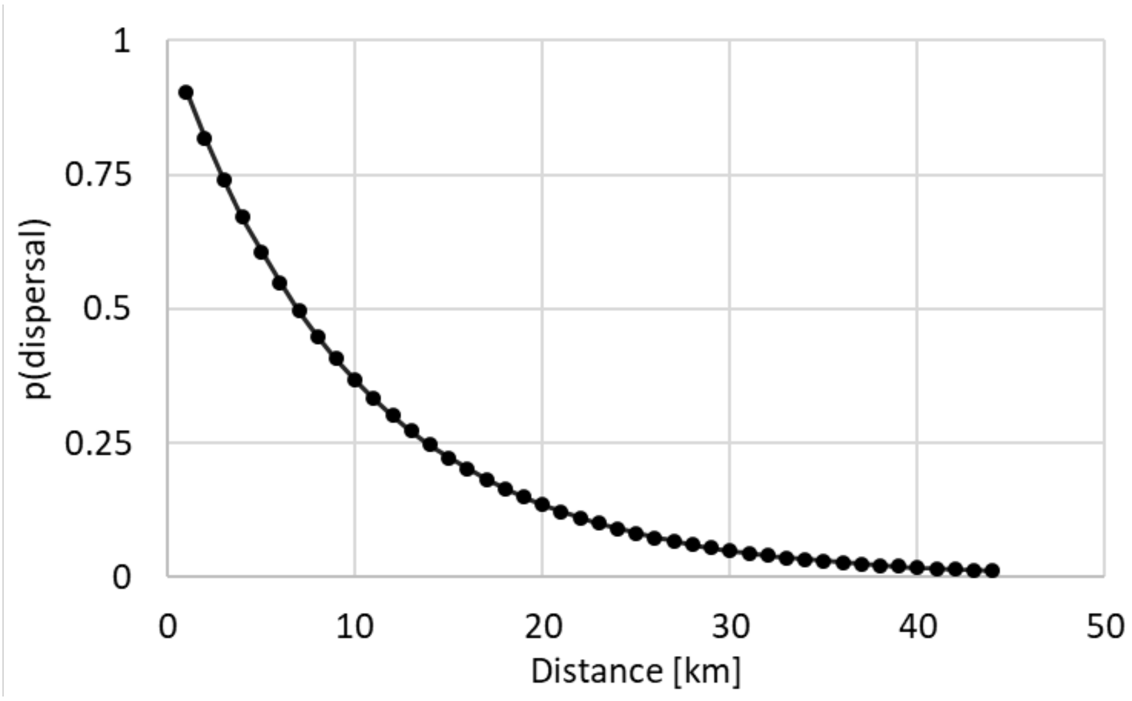


Figure 15 Assumed dispersal probability as a function distance

Platypuses sometimes disperse overland, but no knowledge exists with regards to rates or survival (Gongora et al. 2012; Kolomyjec et al. 2009; Martin et al. 2018). Given the computational difficulties of calculating distances between every stream end in the upper catchments across to different catchments (i.e., over a ridge line), due to the large number of pairs, we assumed that populations with shared overland boundaries (not along the river network) were permeable to low levels of overland dispersal. We conservatively assumed 1% of total dispersal (*P*=0.0025) was overland, calculated proportionally to each of the adjacent population units, given actual rates of overland dispersal were not clear but likely low (Furlan et al. 2013; Kolomyjec et al. 2009). We explored sensitivity of dispersal estimates by assessing variation of ±20% in dispersal rates. The low levels of overland dispersal are likely particularly relevant to minimise inbreeding, an aspect which was not explicitly considered in these models.

Life history

We used a stage-structured population model with values for survival, fecundity, and the probabilities of transition from each life history stage. We assumed a four-stage population structure: females\male and juvenile\adult. Sexual maturity of female platypuses was presumed to start at two years given male platypuses do not produce functional spermatozoa until their second year when they can probably breed (Grant & Temple-Smith 1998; Temple-Smith 1973), although some females do not breed until later than two years (Grant et al. 2004). One to three offspring are produced by a female during a breeding season (Burrell 1927; Grant 1995), although not every female breeds every year (Bino et al. 2015; Grant et al. 2004; Grant et al. 1983). Annual fecundity (*F*) was accordingly calculated as:

F=1.5(average young)·0.5(proportion of females)·0.62(females in the breeding pool)=0.47

Fecundity rates likely vary with resource availability and other population-level factors such as population size and sex ratio but requiring further research. We assumed a polygynous mating system, where each male can mate with up to 3 females (Thomas, J. pers comm) and also inferred from their behaviour and territoriality during the breeding season (Hawke et al. 2021b).

Platypuses can live to at least 21 years in the wild, though most individuals die younger (Grant et al. 2004; Serena et al. 2014). We derived annual, stage-dependant, survival rates (Bino et al. 2015; Bino et al. 2019; Fox et al. 2004), with variation (sd) on vital rates assumed to be 10% for fecundities and 5% for survival. Density dependence was assumed to be a contest and affect both survival and fecundity (Beverton & Holt 1957). Under these assumptions, growth rate (lambda) was 1.02.

To estimate population sizes to underpin metapopulation viability models, we used developed habitat suitability and estimates of platypus densities vary (Table 6). As density estimates range between 3.5 and 6.3, we assumed an overall density of 4 km^{-1}. See above 'Estimated current population size' section for more information.

Incorporating threats to metapopulation models

We focused on measuring the synergistic impacts of threatening processes on platypus population viability. In particular, we examined the impacts of fragmentation (by dams, invasive species, and land modification), reduced carrying capacity and increased likelihood of droughts, projected by climate change (Bino et al., 2019).

Riverine species, with dendritic metapopulation structure as a series of watersheds and linear habitats (rather than a patch and matrix of 2-dimentational metapopulations), can be particularly susceptible to fragmentation from both barriers as well as habitat destruction (Fagan 2002; Campbell Grant 2011). To examine possible fragmentation by large dams (Nilsson et al. 2005), we used the Degree of Fragmentation (DOF) developed for global rivers (Grill et al. 2019) which incorporated the effects of large dams (≥15 m high and ≥0.1 km^3 storage capacity) on discharge and was scaled as a proportion from 0 to 100%. We then use the DOF as a scaling factor impacting longitudinal movements between population units. With regards to limitations to platypus overland dispersal, there was anecdotal evidence that invasive red foxes (*Vulpes vulpes*) (Grant & Fanning 2007) and perhaps cats (*Felis catus*) and domestic dogs prey on platypuses. Platypuses may be particularly vulnerable to predation when moving overland (Grant and Temple-Smith, 2003). We collated 65,827 fox and 13,469 cat observations (1760-2017) from the national Atlas of Living Australia and atlas records held by individual states and territories (ACT Wildlife Atlas Records, 2018; BioNet Atlas of NSW Wildlife, 2018; Tasmania Natural Values Atlas, 2018; Victorian Biodiversity Atlas, 2018; WildNet Queensland Wildlife Data, 2018). Fox and feral cat sightings were recorded respectively in 231 sub-catchments (88%) and 231 sub-catchments (87%), where platypus records occurred, effectively the species' entire distribution. Land clearing and modification also increases predation rates, thermal exposure, erosion and sedimentation as well as forming physical barriers, further limiting overland dispersal (Bino et al. 2019).

Riparian vegetation is a key determinant of water quality and riverine ecosystem health (Bunn et al. 1999; Allan 2004). Physical degradation of platypus habitat occurs by clearing both riparian and catchment-scale vegetation, increasing bank erosion, destroying shelters and burrows for breeding, with sedimentation filling pools and reducing food availability (Bino et al. 2019). Riparian vegetation is also important for organic inputs into streams which supports the entire food chain such as macroinvertebrates, the prey of platypuses (Marchant & Grant 2015). Shading provided by trees also offers thermal dampening (Ray et al. 2003). Without direct measure of habitat quality attributes, we rely on land clearing rates as a surrogate for changes to overall habitat quality.

Thus, to assess the impact of this habitat degradation, we used the proportion of remnant trees as the impact on population carrying capacity. Extensive land clearing across the states of Victoria, New South Wales and South Australia had occurred during the 20th century (Bradshaw 2012; Evans 2016), and continues, particularly in Queensland in recent decades (Reside et al. 2017). By 1980s, almost 40% of Australia's forests had been severely modified by clearing (Wells et al. 1984). Although most land clearing occurred in south-eastern Australia from the turn of the of 19th century to the mid-20th century (Bradshaw 2012), other processes impacting freshwater habitat such as sedimentation are ongoing (Bartley et al. 2014; Reside et al. 2017). We compared reconstructed vegetation cover before European settlement (1788) and mapped vegetation cover in 1988 (Geoscience Australia 2003a; Geoscience Australia 2003b). Thus, to anchor our models in time, we assume our models begin between 1920 and 1960. We consolidated tree classes (tall trees >30m, medium trees <20m, low trees <10m) and calculated the proportion of cleared tree area in each population unit. We then linearly scaled land clearing as the impact to population's estimated carrying capacity. We also tested the sensitivity of models by examining a systematic reduction of carrying capacity at 20% increments (20%-80%) across all populations.

We also assessed the impacts of severe natural droughts, incorporated as 'catastrophes' in our meta-population models. For freshwater species, droughts can lower survival depending on the intensity and duration of droughts, the existence of refugia pools, availability of food, and increased mobility of animals (Lennox et al. 2019; Kinlaw 2004; Ruiz-Olmo et al. 2001; Vander et al. 2020). In platypuses, severe droughts impact freshwater habitat (Grant & Fanning 2007) and prey availability (Marchant & Grant 2015), increasing mortality (Griffiths et al., 2019) and reduce fecundity (Serena et al. 2014). During the Millennium Drought significant declines in platypus numbers and in some areas caused disappearance of platypuses altogether were recorded in Victoria (Mitrovski 2008; Griffiths et al. 2019). We incorporated past and future climate, across the platypus's range, using the Australian Natural Resource Management (NRM) units (CSIRO and Bureau of Meteorology 2015). Across NRM units, between 1975-1995, median range was 0.9-1.5 extreme droughts, with a median duration of 22-38 months across the platypus's range (CSIRO and Bureau of Meteorology 2015). We calculated annual historical probabilities of these extreme droughts for each population (based on NRM units) and explored a range of impacts between 10% - 30% on platypus mortality. We also analysed projected impacts of climate change (Representative Concentration Pathway (RCP) 2.6, 4.5, 8.5), on median frequency of extreme drought events, projected to increase in frequency (55%-320%) and duration (4%-38%) across NRM regions by 2070 (CSIRO and Bureau of Meteorology 2015) and similarly explored a range of impacts in our metapopulation models of 10%, 20% and 30% on platypus mortality.

Models

To establish a baseline scenario, we first simulated 1,000 replicates of metapopulation dynamics for 200 years to achieve an equilibrium, using RAMAS GIS 5.1 (Akçakaya and Root, 2013). We then used derived baseline results of 506 viable populations to simulate population dynamics and metapopulation occupancy, as a measure of extinction risk, using several scenarios of threatening processes. For each scenario, we ran 1,000 replicates for 200 years. We used the same set of initial population sizes for all simulated scenarios. We evaluated impacts on populations, based on population occupancy (number of populations with platypuses) and Effective Minimum Population (EMP), a widely used metric for species' recovery and conservation management programs (McCarthy and Thompson 2001; Clark et al., 2002), although it may not sufficiently measure long-term persistence and evolutionary potential (Trail et al. 2010). We evaluated the sensitivity of our model assumptions on metapopulation occupancy and EMP on our baseline models, following 200 years of simulation by varying the maximum growth rate (Rmax) by ±5% and the stage matrix estimates (survival and fecundity) by ±10%. We also examined the effect of reducing the number of females a male can mate with from three to two.

Nearly a third (153) of the 506 baseline populations of the metapopulation models had at least one dam within the population boundary. Once integrated within the metapopulation model, degree of fragmentation and restricted overland dispersal projected extinction of 58 population units (11.5%), and reduction of 12.9% in the Effective Minimum Population (EMP). Almost a third of initial population units lost latitudinal connectivity with other population units. Reductions predominantly occurred in populations units in the headwaters of catchments, a result of isolated small population sizes coupled with modelled environmental and demographic stochasticity. Incorporating fragmentation predicted significant loss of connectivity across the species' entire range and increased extinction risk, with a predicted decline in population size greater than 50% in 43% of population units (Figure 16 and Figure 17).

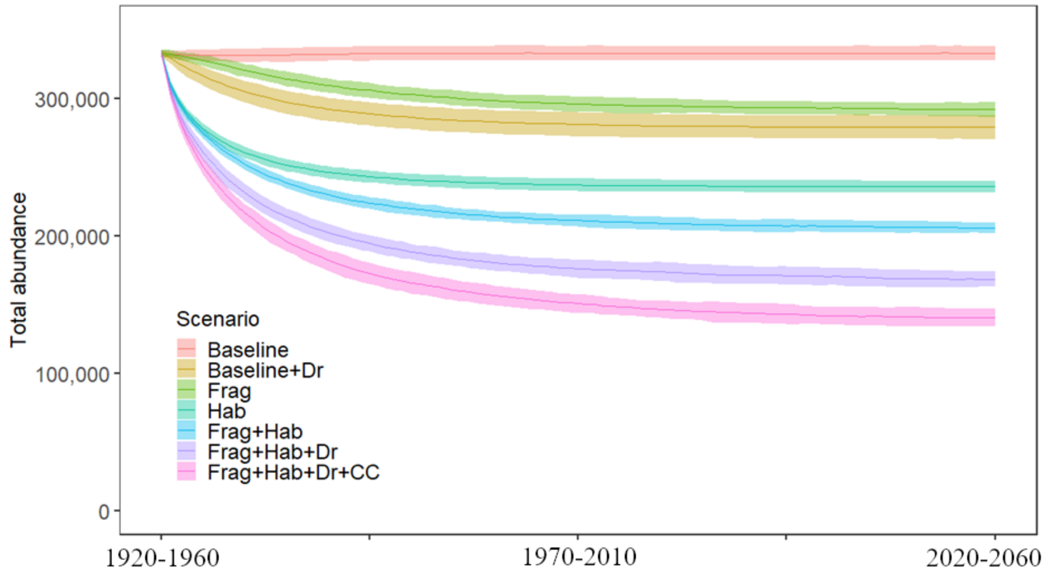


Figure 16 Predicted total number of platypuses over 100 years of metapopulation models under explored scenarios (Baseline, Dr – droughts at historic frequencies with 20% mortality, Frag – fragmented populations using DOF and limited overall dispersal, Hab – reduced carrying capacity scaled by tree clearing, CC – increased drought frequencies and severity under project climate change).

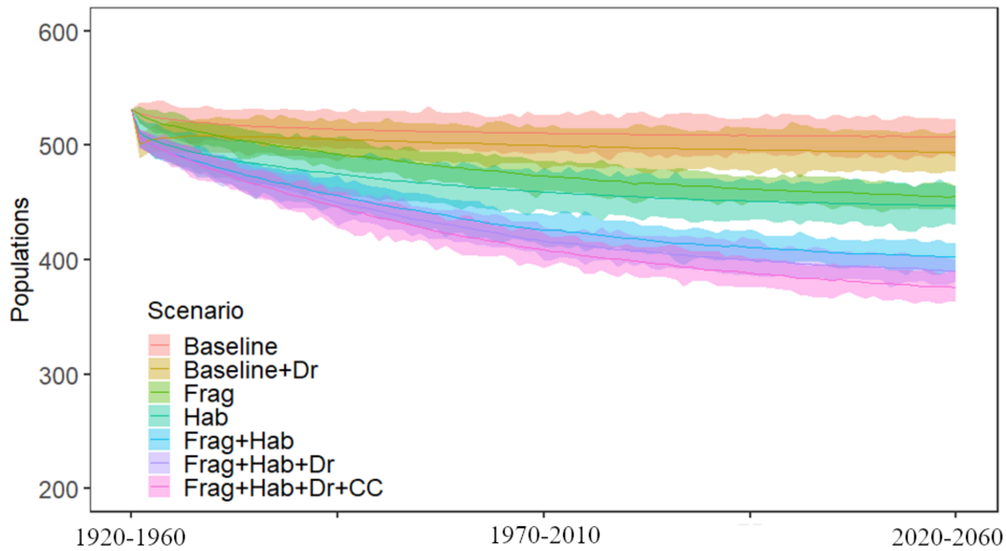


Figure 17 Predicted total number of platypus populations (hybas7) over 100 years of metapopulation models under explored scenarios (Baseline, Dr – droughts at historic frequencies with 20% mortality, Frag – fragmented populations using DOF and limited overall dispersal, Hab – reduced carrying

capacity scaled by tree clearing, CC – increased drought frequencies and severity under project climate change).

Mapped 1988 vegetation cover compared to 1788, showed significant loss of tree cover has occurred where platypuses occur, including an estimated loss of 40% of low trees (<10m), 30% of medium trees (10-30m), and 20% of tall trees (>30m). Such habitat destruction was estimated to reduce carrying capacity by 26%±34sd across all populations (assuming linear relationship between land clearing and reduction in carrying capacity), reducing metapopulation occupancy by 12.8% and EMP by 29.3% from the baseline model. Population declines were predicted to mostly occur along the western extent of the platypus distribution, predominantly affecting the rivers of the Murray-Darling Basin, correlating with the most severe observed declines from platypus records. A systematic reduction of population carrying capacity across all populations, at 20% increments (20%-80%), reduced metapopulation occupancy respectively by 4%, 10%, 19% and 32%, compared to the baseline model, while the impact on EMP was more extreme, with respective reductions of 21%, 42%, 63%, and 83% (Figure 16 and Figure 17).

When habitat destruction was coupled with the fragmentation impacts of dams and loss of overland dispersal, metapopulation occupancy was reduced by 23.1% and EMP by 39.2%. This combined scenario was estimated to reduce total population abundance by half from the pre-European baseline across 79% of populations, leaving a scattering of more resilient, but less connected populations in areas of core suitability. Following a systematic reduction of population carrying capacity across all populations, at 20% increments (20%-80%), along with fragmentation scenario, synergistically reduced metapopulation occupancy further between 14.6% and 43.1%, with respective reductions in EMP between 32.1% to 86.9%. These were significantly higher compared to un-fragmented populations, indicating high sensitivity of platypus to fragmentation and movement barriers (Figure 16 and Figure 17).

Incorporating historical severe drought frequencies, representing likely baseline scenarios, with impacts ranging from a reduction by 10% to 30% did not have a significant impact on metapopulation occupancy, decreasing number of populations respectively by 1.4% to 6.3%, though commensurate decreases in EMP of 8.1% and 27.6% resulted. However, the combined synergistic scenario, incorporating habitat destruction and fragmentation with historic drought frequencies (10%-30% reduction in population abundance), reduced metapopulation occupancy between 24.3% to 30.0% and EMP between 45.0% and 58.1%, compared to the baseline. The 20% impact scenario was estimated to reduce total population abundance by half across 88% of populations. With increased frequency and duration of droughts under climate change, combined with fragmentation and habitat destruction, metapopulation occupancy was estimated to decrease between 26.1% to 38.3%, a reduction between 49.4% and 71.1% in EMP, leaving only small and isolated populations in Tasmania and the east coast (Figure 16 and Figure 17). These climate change scenarios only consider the impact of droughts on populations and do not take into account changes to the species' fundamental niche (see 'Climate change' below).

Sensitivity of metapopulation occupancy and EMP to variation of ±10% in vital rates estimates (Bino et al. 2020) was low and eclipsed by the impacts of examined threatening processes (Table 9). EMP was moderately sensitive to variation in maximum growth rate (Rmax), with a 5% decrease in Rmax (λ=1.045) leading to a 10.7% decrease in EMP and 6.1% in metapopulation occupancy from the baseline model. When Rmax was increased by 5% (λ=1.155), EMP increased by 1.9% and metapopulation occupancy increased by 6.9%. The largest sensitivity was observed when the number of females a male can mate with was reduced from three to two, lowering EMP and metapopulation occupancy by 39.7% and 73.3%, respectively (Table 9).

As estimates of EMP were dependant on several assumptions relating to modelled habitat availability and platypus densities, their accuracy remains to be refined, but nonetheless these models provide a relative measure of the synergistic impacts of threatening processes to populations sizes and viability. While these models suggest declines in metapopulation occupancy and EMP as a direct consequence of lowered carrying capacity, survival, and isolation, they do not incorporate genetic information, likely to exacerbate these declines given losses in genetic variation across the range due to fragmentation.

Table 9 Details of examined metapopulation model scenarios and results (see Bino et al. 2020)

Scenario ID	Fragmentation scenario (%Δ Dispersal rate)	Carrying Capacity (%Δ)	Catastrophe Probability\reduced abundance	Stage matrix mean (%Δ)	Max growth rate	Mating (male: female)	Metapopulation occupancy (min – max)	Total abundance (min – max)	EMP ±SD
Base	Baseline	0%	0	0	1.1	1:3	506(490-522)	333198(324259-341692)	326804±1339
K-20%	Baseline	-20%	0	0	1.1	1:3	488(465-512)	262868(255159-269701)	258082±1330
K-40%	Baseline	-40%	0	0	1.1	1:3	458(440-478)	193059(187727-198605)	189550±993
K-60%	Baseline	-60%	0	0	1.1	1:3	410(391-430)	124234(120808-128793)	121653±784
K-80%	Baseline	-80%	0	0	1.1	1:3	342(317-360)	55239(52470-58381)	53701±545
Dis±20%	Baseline (±20%)	0%	0	0	1.1	1:3	510(490-528)	321225(312575-331412)	315533±1440
Dis±10%	Baseline (±10%)	0%	0	0	1.1	1:3	508(494-525)	327199(320388-336898)	321243±1428
Dis-10%	Baseline (-10%)	0%	0	0	1.1	1:3	503(487-521)	339050(331136-347396)	330375±1472
Dis-20%	Baseline (-20%)	0%	0	0	1.1	1:3	500(481-518)	344830(336389-354069)	331293±1445
FragDam	Fragmentation (dams only)	0%	0	0	1.1	1:3	478(463-493)	290742(285530-298380)	284697±1441
Frag	Fragmentation	0%	0	0	1.1	1:3	448(439-460)	290951(285563-297599)	284536±1549
Frag/K-20%	Fragmentation	-20%	0	0	1.1	1:3	432(421-449)	227471(219179-233293)	221860±1379

Scenario ID	Fragmentation scenario (%Δ Dispersal rate)	Carrying Capacity (%Δ)	Catastrophe Probability\reduced abundance	Stage matrix mean (%Δ)	Max growth rate	Mating (male: female)	Metapopulation occupancy (min – max)	Total abundance (min – max)	EMP ±SD
Frag/K-40%	Fragmentation	-40%	0	0	1.1	1:3	403(388-417)	164267(159646-169660)	160447±1143
Frag/K-60%	Fragmentation	-60%	0	0	1.1	1:3	354(342-370)	103615(100964-106373)	100591±782
Frag/K-80%	Fragmentation	-80%	0	0	1.1	1:3	288(275-301)	44582(42904-46659)	42659 ±529
Hab	Baseline	Landuse	0	0	1.1	1:3	441(420-463)	235506(227494-244712)	230921±1246
Hab/Frag	Fragmentation	Landuse	0	0	1.1	1:3	389(378-399)	204289(199152-209551)	198558±1270
Dr-10%	Baseline	0%	Historic drought/-10%	0	1.1	1:3	438(425-446)	252946(247651-262494)	300184±1726
Dr-20%	Baseline	0%	Historic drought/-20%	0	1.1	1:3	421(401-436)	211382(201075-220693)	269784±2772
Dr-30%	Baseline	0%	Historic drought/-30%	0	1.1	1:3	390(368-405)	167909(155842-181727)	236709±3660
Hab/Frag/Dr-10%	Fragmentation	Landuse	Historic drought/-10%	0	1.1	1:3	383(368-396)	186295(180587-191463)	179586±1807
Hab/Frag/Dr-20%	Fragmentation	Landuse	Historic drought/-20%	0	1.1	1:3	371(357-381)	166560(158368-175152)	158991±1915
Hab/Frag/Dr-30%	Fragmentation	Landuse	Historic drought/-30%	0	1.1	1:3	354(338-371)	145368(133994-155104)	136864±2681
Hab/Frag/DrCC-10%	Fragmentation	Landuse	Climate change drought/-10%	0	1.1	1:3	374(356-396)	171463(164011-180582)	165516±1777

Scenario ID	Fragmentation scenario (%Δ Dispersal rate)	Carrying Capacity (%Δ)	Catastrophe Probability\reduced abundance	Stage matrix mean (%Δ)	Max growth rate	Mating (male: female)	Metapopulation occupancy (min – max)	Total abundance (min – max)	EMP ±SD
Hab/Frag/DrCC-20%	Fragmentation	Landuse	Climate change drought/-20%	0	1.1	1:3	350(337-363)	137516(130558-145184)	130481±2302
Hab/Frag/DrCC-30%	Fragmentation	Landuse	Climate change drought/-30%	0	1.1	1:3	312(292-329)	101448(93376-113263)	94574±3023
Frag/Dis±20%	Fragmentation (±20%)	Landuse	Historic drought/-10%	0	1.1	1:3	300(274-323)	153180(146872-160412)	149747±1713
Frag/Dis±10%	Fragmentation (±10%)	Landuse	Historic drought/-10%	0	1.1	1:3	320(286-343)	163025(155785-171525)	159597±1819
Frag/Dis-10%	Fragmentation (-10%)	Landuse	Historic drought/-10%	0	1.1	1:3	356(331-378)	189404(180491-199079)	185213±1778
Frag/Dis-20%	Fragmentation (-20%)	Landuse	Historic drought/-10%	0	1.1	1:3	370(345-389)	202748(192987-209908)	198195±1637
CatP0.1-10%	Baseline	0%	0.1/-10%	0	1.1	1:3	496(478-515)	293414(283690-305892)	286603±1969
CatP0.1-20%	Baseline	0%	0.1/-20%	0	1.1	1:3	479(458-495)	250464(237005-267481)	241591±3008
CatP0.1-30%	Baseline	0%	0.1/-30%	0	1.1	1:3	450(426-472)	203675(184565-227984)	193049±4102
Frag/CatP0.1-10%	Fragmentation	0%	0.1/-10%	0	1.1	1:3	446(427-460)	251289(243545-257486)	245905±1799
Frag/CatP0.1-20%	Fragmentation	0%	0.1/-20%	0	1.1	1:3	428(411-440)	210174(200282-217759)	203255±2860
Frag/CatP0.1-30%	Fragmentation	0%	0.1/-30%	0	1.1	1:3	394(373-414)	166818(154114-178742)	158757±3835

Scenario ID	Fragmentation scenario (%Δ Dispersal rate)	Carrying Capacity (%Δ)	Catastrophe Probability\reduced abundance	Stage matrix mean (%Δ)	Max growth rate	Mating (male: female)	Metapopulation occupancy (min – max)	Total abundance (min – max)	EMP ±SD
Poly2	Baseline	0%	0	0	1.1	1:2	451(431-475)	173090(165300-179928)	169537±1779
Hab/Frag/Dr-10%/Poly2	Fragmentation	Landuse	Historic drought/-10%	0	1.1	1:2	305(288-323)	76648(71210-82620)	74050 ±1484
Mat-10%	Baseline	0%	0	-10%	1.1	1:3	505(485-522)	333215(323867-342314)	326766±1423
Mat-5%	Baseline	0%	0	-5%	1.1	1:3	506(488-525)	333161(324101-343003)	326776±1415
Mat±5%	Baseline	0%	0	±5%	1.1	1:3	505(486-526)	332983(322783-342201)	326791±1403
Mat±10%	Baseline	0%	0	±10%	1.1	1:3	505(483-524)	333175(323247-343234)	326790±1452
Lam-5%	Baseline	0%	0	0	1.045(-5%)	1:3	475(453-495)	296486(286878-306984)	332873±1304
Lam-2%	Baseline	0%	0	0	1.078(-2%)	1:3	496(479-515)	322348(313998-330749)	331221±1476
Lam±2%	Baseline	0%	0	0	1.122(±2%)	1:3	515(499-533)	341041(332352-349451)	316478±1659
Lam±5%	Baseline	0%	0	0	1.155(±5%)	1:3	541(527-556)	353012(345932-360317)	291722±2329

Threats (See Appendix for additional information)

This section provides evidence in support of a decline in habitat quality, contributing to reductions in platypuses. Threats to platypus populations are widespread across their range and synergistic (Bino et al. 2019).

Vegetation clearing

Riparian vegetation is a key determinant of water quality and riverine ecosystem health rivers (Bunn et al. 1999; Allan 2004). Physical degradation of platypus habitat occurs by clearing both riparian and catchment-scale vegetation, increasing bank erosion, destroying shelters and burrows for breeding, with sedimentation filling pools and reducing food availability (Bino et al. 2019). Riparian vegetation is also important for organic inputs into streams which supports the entire food chain such as macroinvertebrates, the prey of platypuses (Marchant & Grant 2015). Shading provided by trees also offers thermal dampening (Ray et al. 2003). Without direct measure of habitat quality attributes, we rely on land clearing rates as a surrogate for changes to overall habitat quality. Extensive land clearing across the states of Victoria, New South Wales and South Australia had occurred during the 20th century (Bradshaw 2012; Evans 2016), and continues, particularly in Queensland in recent decades (Reside et al. 2017). By 1980s, almost 40% of Australia's forests had been severely modified by clearing (Wells et al. 1984). Although most land clearing occurred in south-eastern Australia from early 19th century to the mid-20th century (Bradshaw 2012), other processes impacting freshwater habitat such as sedimentation are ongoing (Bartley et al. 2014; Reside et al. 2017). While platypuses are known to occur in waterways in cleared agricultural land (Lunney et al. 1998), land clearing is considered a significant threat to their habitat (Bino et al. 2019). Unrestricted livestock access to rivers has caused further degradation of riverbanks through trampling (Lunney et al. 2004). Bank erosion can significantly increase without riparian vegetation for stability, increasing sedimentation and turbidity, further degrading platypus habitat (Figure 18b).

We compared reconstructed vegetation cover before European settlement (1788) and mapped vegetation cover in 1988 (Geoscience Australia 2003a; Geoscience Australia 2003b). We consolidated tree classes (tall trees >30m, medium trees <20m, low trees <10m) and calculated the proportion of cleared tree area in each population unit. Across the distribution of platypus, 31.5% of sub-catchments have had more than a 50% reduction in tree cover (trees 10-30 m) since European colonisation, and 18.4% of these have had a >70% reduction (Figure 18a). Excluding the South Australian Gulf with only one sub-catchment, the Murray-Darling Basin had the greatest average proportion of tree cover loss (0.49±0.32 sd; Table 10), as was the case for the state of NSW (0.36±0.33 sd).

Table 10. The average proportion of tree cover loss in each of the major river basins and states in the IUCN distribution of the platypus.

River Basin	**Average proportion tree cover loss across sub-catchments ±sd**
Gulf of Carpentaria	0.02±0.02
East Coast	0.29±0.30
Murray-Darling	0.49±0.32
South Australian Gulf	0.52
Tasmania	0.41±0.28
State	**Average proportion tree cover loss across sub-catchments**
QLD	0.26±0.29
NSW	0.36±0.33
ACT	0.28±0.22
VIC	0.42±0.35
TAS	0.20±0.21
SA	0.45±0.30

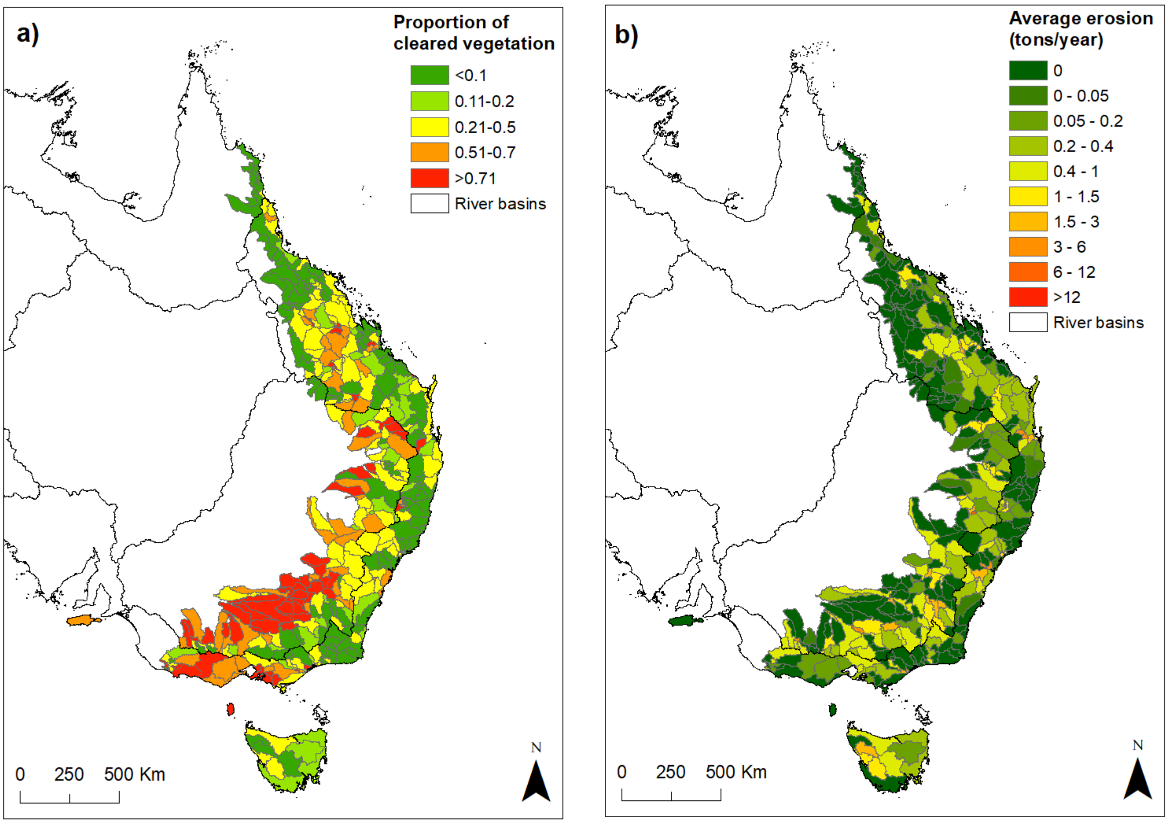
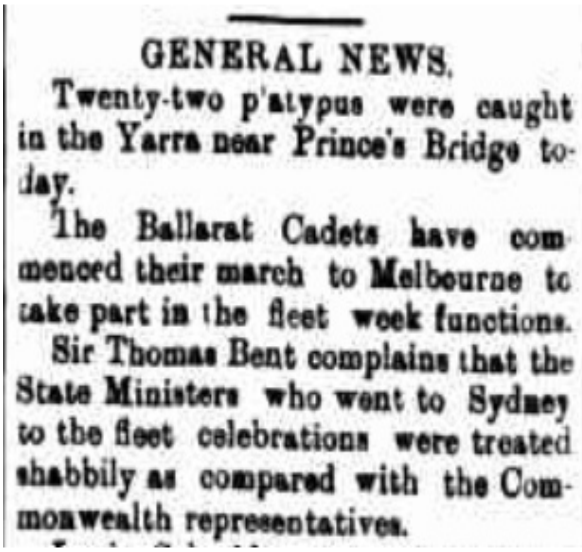


Figure 18. a) Proportion of cleared vegetation across sub-catchments within the current platypus IUCN distribution between 1788-1988 (GeoscienceAustralia 2003b; GeoscienceAustralia 2003a) and b) the weighted average of tons of erosion per year for each sub-catchment within the current IUCN distribution for platypus (Grill et al. 2019).

Urbanisation

Platypuses occupy urban and peri-urban environments but declines and localised extinctions in heavily urbanized areas suggest they are sensitive to urbanisation. Platypus distribution is limited by catchment imperviousness in urban areas and they have disappeared from Melbourne's CBD, now rarely sighted within 15 km of the city (Serena & Pettigrove 2005), though both nest-building behaviour by a gravid female and mating activity were observed and filmed in the Yarra River at Templestowe Lower (15-16 km from the city centre) as recently as September 2020 (M. Serena, pers. comm.). A newspaper report from the Kerang New Times in 1908 (Figure 19), indicates that on the Prince's Bridge on the Yarra River in Melbourne CBD, 22 platypuses were captured, highlighting this decline. Additionally, platypuses have declined from the greater Brisbane region, with eDNA indicating that platypuses have been lost from 24% of sampled waterways where they were previously found (Brunt et al., 2020). Platypuses have also disappeared from the metropolitan areas of Sydney and Wollongong

(Grant 1998). Urban streams have high flow variability, with extended periods of reduced baseflows and increased magnitude and frequency of high flows (Bino et al. 2019). High flow events in urban environments may increase foraging energetics (Bethge 2002) and reduce recruitment (Bino et al. 2015; Serena & Grant 2017). Decreased baseflows also reduce habitat quality and increase predation risks. Urbanisation is also associated with increased water pollution, including litter entanglement and roadkill (Serena & Williams 1998; Serena & Williams 2010), and high concentrations of pharmaceuticals in the diet of platypuses (Richmond et al. 2018).


GENERAL NEWS.

Twenty-two p'atypus were caught in the Yarra near Prince's Bridge to-day.

The Ballarat Cadets have commenced their march to Melbourne to take part in the fleet week functions.

Sir Thomas Bent complains that the State Ministers who went to Sydney to the fleet celebrations were treated shabbily as compared with the Commonwealth representatives.

Figure 19. Newspaper cutting from the Kerang New Times, August 1908.

River regulation

Water resource development, including the building of dams and extraction of water poses a significant threat to platypuses. The distribution of the platypus overlaps significantly with Australia's most regulated rivers, with dams being present in 40.8% of sub-catchments in which platypuses have been recorded (Figure 20a). Of these, 14% have more than four dams present within the sub-catchment (Figure 20b). Large dams also contribute to fragmentation between basins and rivers (Figure 20c).

The river basins most heavily impacted by dams (excluding the South Australian Gulf) were the Murray-Darling Basin (45.3% of sub-catchments have dams) and Tasmania (100%; Table 11). Tasmania and Victoria were the two states most affected by dams, with dams being present in 100% and 41.3% of sub-catchments, respectively (Table 11).

Table 11. The number of dams and the percentage of sub-catchments with dams in the IUCN distribution of platypuses within each major river basin and state.

Basin	**Number of dams in IUCN distribution**	**% of sub-catchments with dams**
Gulf of Carpentaria	4	8.3
East Coast	327	35.2
Murray-Darling	179	45.3
South Australian Gulf	1	100
Tasmania	73	100
State	**Number of dams in IUCN distribution**	**% of sub-catchments with dams**
QLD	164	28.0
NSW	173	40.4
ACT	5	28.6
VIC	167	41.3
TAS	73	100
SA	1	25.0

Significant alterations to flow regimes, including the timing and temperature of flows can significantly impact platypus abundances downstream of these regulatory structures (Hawke et al. 2021a). It is also probable that large dams impede platypus dispersal over water and land, potentially reducing genetic diversity and breeding capabilities and increasing the risk of extinction (Furlan et al. 2012). A recent study currently in progress (Mijangos et al. unpublished data), investigated genetic estimates of exchange per-generation collected from platypuses in three catchments (Border Rivers, Snowy Rivers, Upper Murray Rivers). Within each catchment, platypus samples were collected from above and below large dams as well as to an adjacent free flowing river. Preliminary results indicated that the dams restrict lifetime dispersal of platypus. This restricted dispersal is expected to have both short-term and medium-term impacts. In the short term, reduced dispersal will limit the ability of one part of the river to recolonize another part that has experienced adverse effects. In the medium term, dividing the river into two separate populations, that must be smaller than the entire pre-dam population, is expected to lead to loss of genetic diversity which in-turn reduces survival and breeding, as well reducing the ability of populations to respond to environmental change (Frankham et al.

2002; Allendorf & Luikart 2007). In addition, a range of water resource development projects involving the building of dams and diversion of water are planned that intersect with the current distribution of platypus (Dungowan Dam proposal).

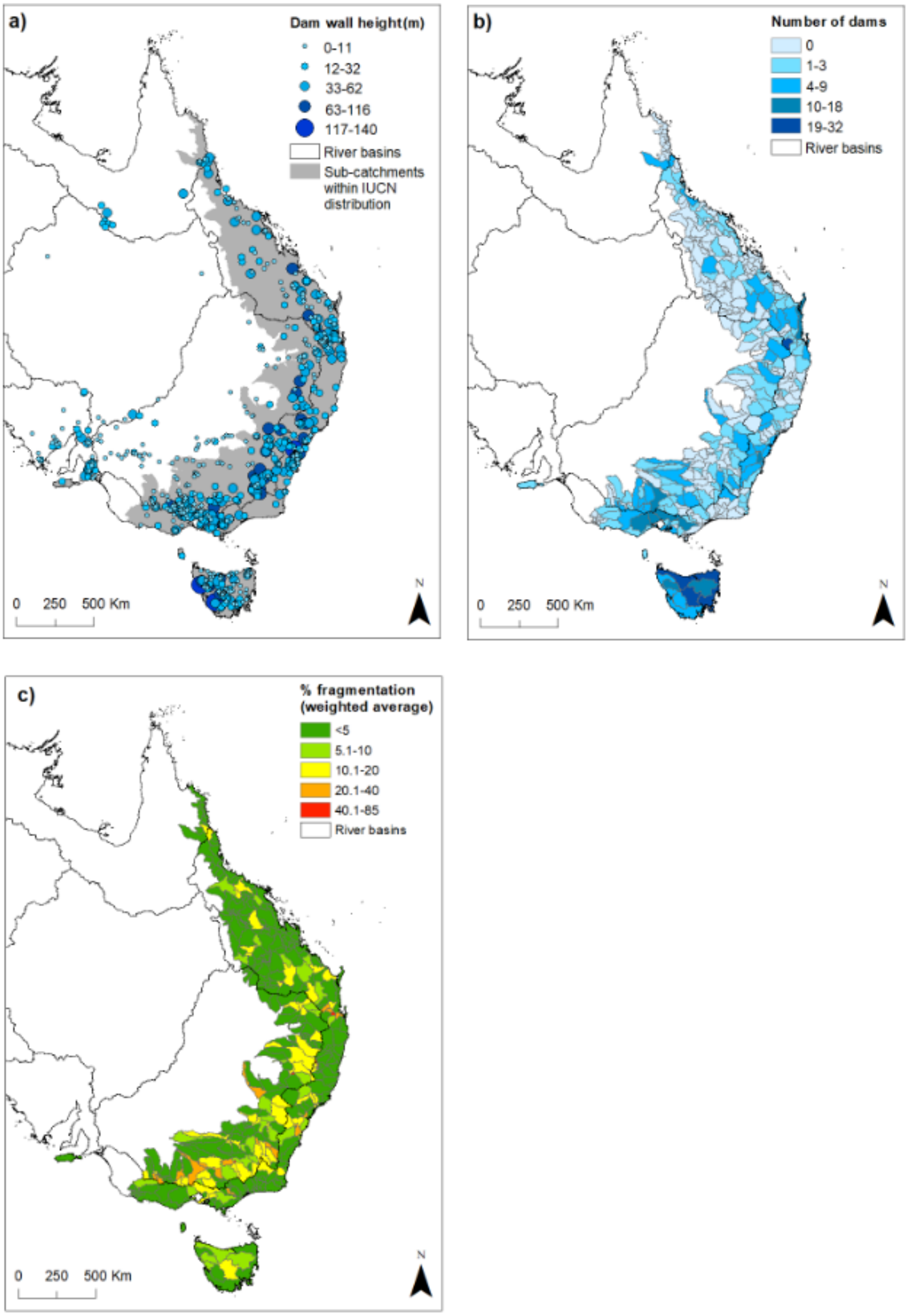


Figure 20. a) The height of dam walls across eastern Australian, b) the number of dams in sub-catchments within the current IUCN distribution of platypus (Australian Government 1990) and c) the weighted average percent fragmentation (Grill et al. 2019) in each sub-catchment within the current IUCN distribution for platypus.

Fishing by-catch, predation & pollution

Platypuses are susceptible to predation by red foxes (*Vuples vuples*) and dogs (*Canis familiaris*) (Grant & Fanning 2007), with anecdotal evidence of predation by feral cat (*Felis catus*). Enclosed traps (e.g. Opera house style), which are used to capture fish and crustaceans, frequently drown platypuses which become trapped inside and cannot escape. In Victoria, where mortality was tracked and could be assigned, 56% of 186 platypus mortalities (1980–2009) were caused by drowning in illegal nets or enclosed traps (Serena and Williams 2010a). The Victorian Fisheries Authority announced a state-wide ban on enclosed traps in 2019, but they can still be used in private waters in NSW and QLD and are still used illegally in some public waters where platypuses occur. The nature of platypus foraging also makes them particularly susceptible to entanglement around their neck and torso by plastic, fishing line, and rubber bands.

Disease

Platypuses are infected by a number of pathogenic organisms (Munday et al. 1998), but the major disease impacting morbidity and mortality is caused by the fungal infection *Mucor amphibiorum*, currently restricted to some Tasmanian populations. The disease has a low-level, ongoing impact, with little evidence of declines in infected areas (Gust & Griffiths 2011). The prevalence of the disease was initially high (mean of surveys between 1994 and 2005; 0.295), but has since decreased (0.071), although early surveys targeted diseased areas. The disease is still present in some populations (Connolly 2009; Gust et al. 2009).

Climate change

Climate change is impacting platypuses by reducing suitable habitats across their range, affecting distribution and abundances. During the recent (2017-2019) extreme drought across much of eastern Australia (in some areas the worst in over 120 years of records; BOM Webinar 18 July 2019), many incidences of platypus distress and mortality were reported in the media as well as through private communications with WIRES, zoos, and platypus conservation groups.

Reductions to river flows due to increased dry periods and increases in temperature are predicted to have a significant impact on the future survival of the species in its northern extent (Klamt et al. 2011). Drying of streams and refuge pools will increase overland movements that make platypuses more susceptible to predation and air temperatures in excess of their upper thermal tolerance of over 30°C (Robinson 1954). Increases in drought frequency and severity are predicted to reduce the total population abundance of platypuses by up to 73% within the next 50 years (Bino et al. 2020). Increasing human water demands during drought conditions will increase stress on water sources with regulation of rivers with dams likely exacerbating these impacts (Klamt et al. 2011).

We examined predicted changes to the platypus' climatic niche (i.e., abiotic conditions) by developing a species distribution model which considered all observations of the platypus (14,848; 1858-2020). We modelled habitat suitability for platypuses using the Biodiversity & Climate Change Virtual Lab and the Maximum Entropy Species Distribution Modelling approach (Phillips & Dudik 2008). We considered four environmental variables of contemporary climate (Annual Mean Temperature, Max Temperature of Warmest Month, Annual Precipitation, Precipitation of Driest Quarter; 1976-2005 (Xu & Hutchinson 2013) at a scale of 1km. We then predicted future suitability under established Representative Concentration Pathways (RCPs) (Van Vuuren et al. 2011) of total radiative forcing produced by human greenhouse gas emissions resulting from different combinations of economic, demographic and institutional futures (IPCC 2018). We evaluated two future climate modes, the CSIRO Global Climate Model Mk 3.0 (GCM Mk3), (Vanderwal 2012) and the Hadley Centre Coupled Model version 3 (HadCM3), Gordon et al. 2000) to predict future climate conditions under RCP 2.4, 4.5, 6.0, and 8.5 for 2025 – 2065 at 10-year intervals. Current emissions are consistent with the RCP8.5 model (Schwalm et al. 2020).

Based on developed habitat suitability model and climate change emission scenarios, by 2055, platypus suitable climatic niche was predicted to contract between 24% (RCP 2.6) and 43% (RCP 8.5) under the HadCM3 model, or between 5% (RCP 2.6) and 17% (RCP 8.5) under GCM Mk3 model, (Figure 21) by 2055. Contraction mostly occurred in the northern and western regions of its range (Figure 22 and Figure 23). Although significant uncertainties regarding future climate exist, models based on a species' climatic niche likely underestimate impacts of climate change, which would increase drought frequencies and intensity (CSIRO and Bureau of Meteorology 2015) as well as impact meta-population dynamics as considered in the previous section.

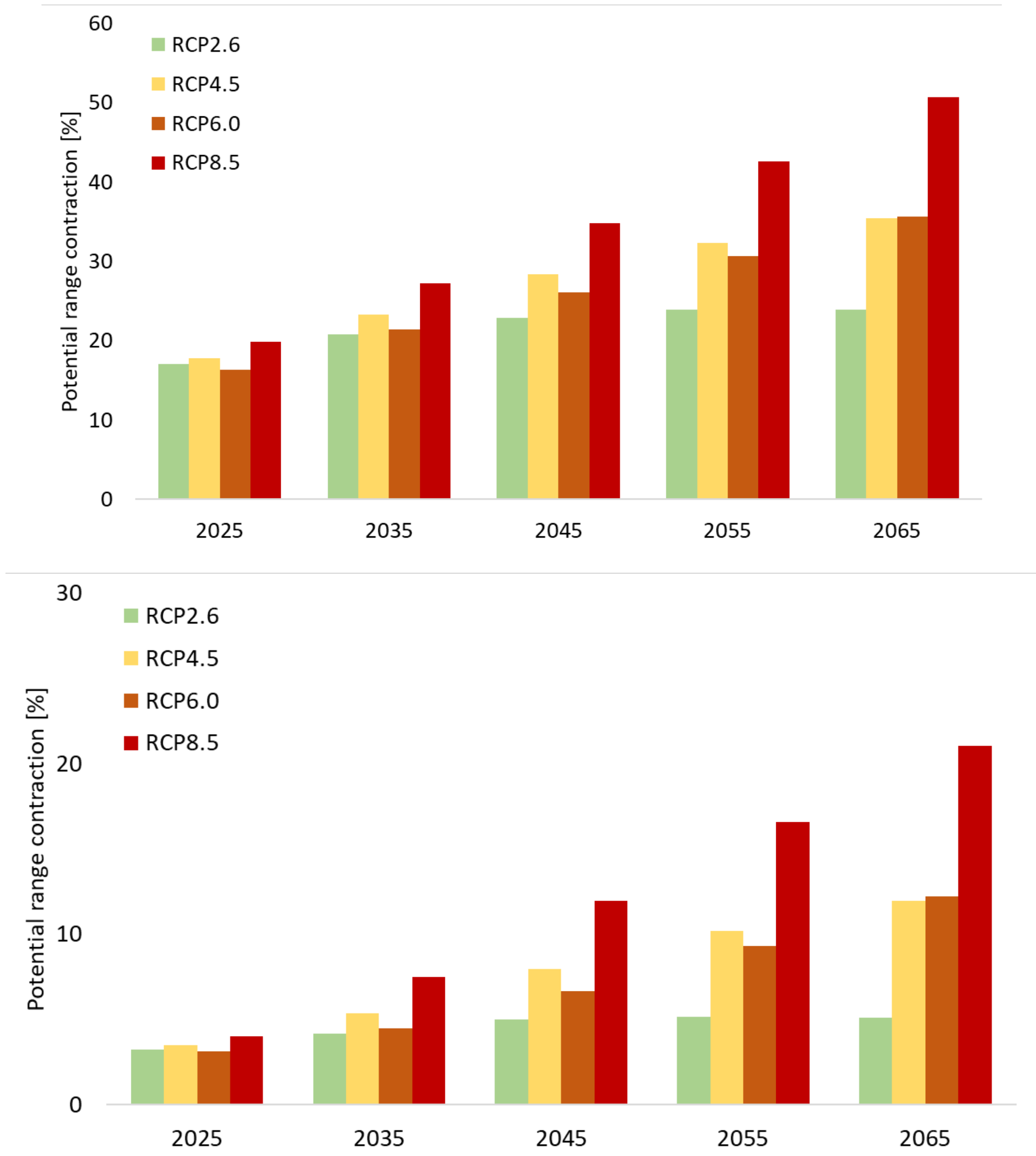


Figure 21. Change in estimated climatically suitable area under RCP climate change scenarios using (top) HadCM3 and (bottom) GCM Mk 3.0

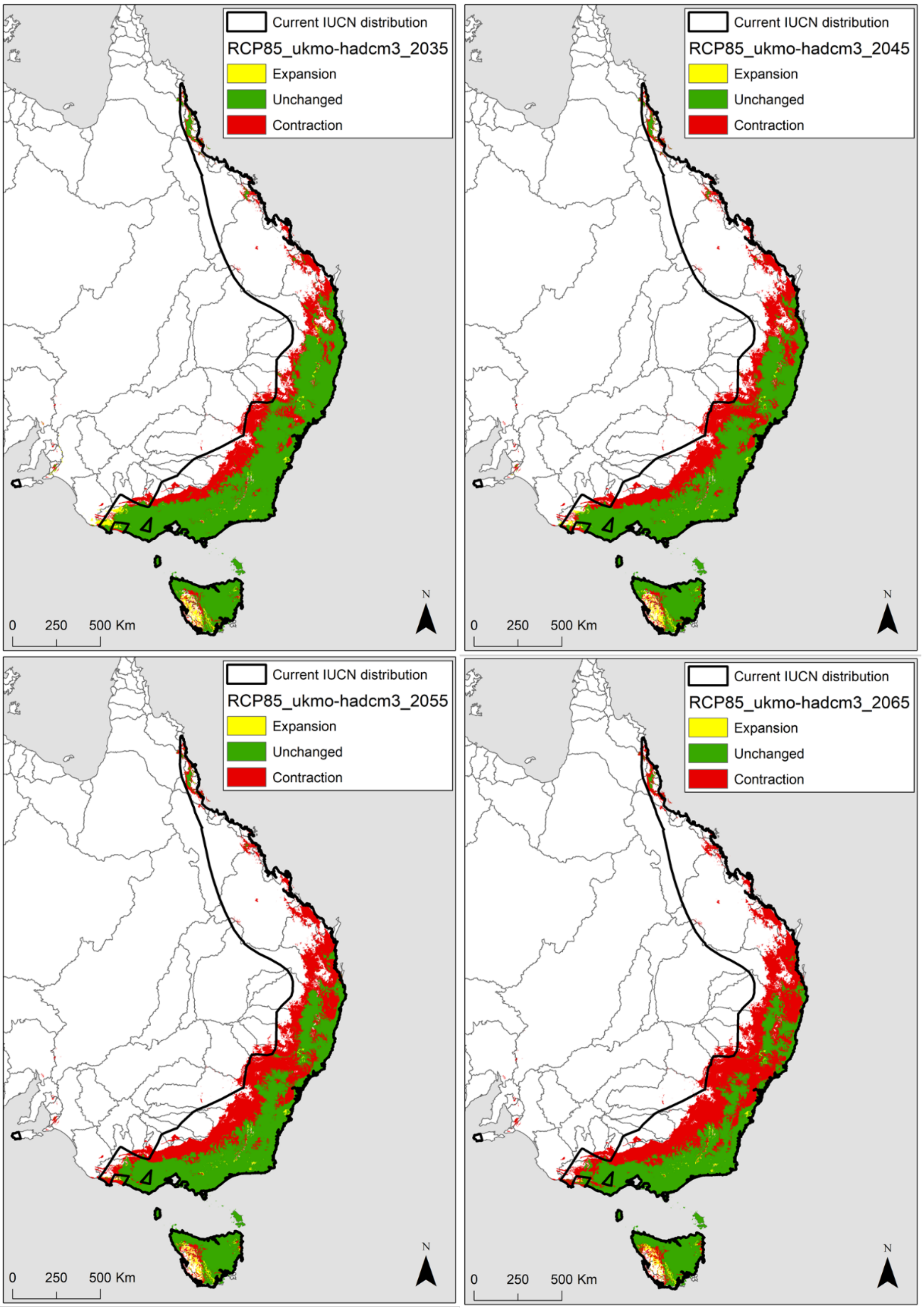


Figure 22 Change in estimated climatically suitable area of under RCP 8.5 HadCM3 climate change scenarios between 2035-2065

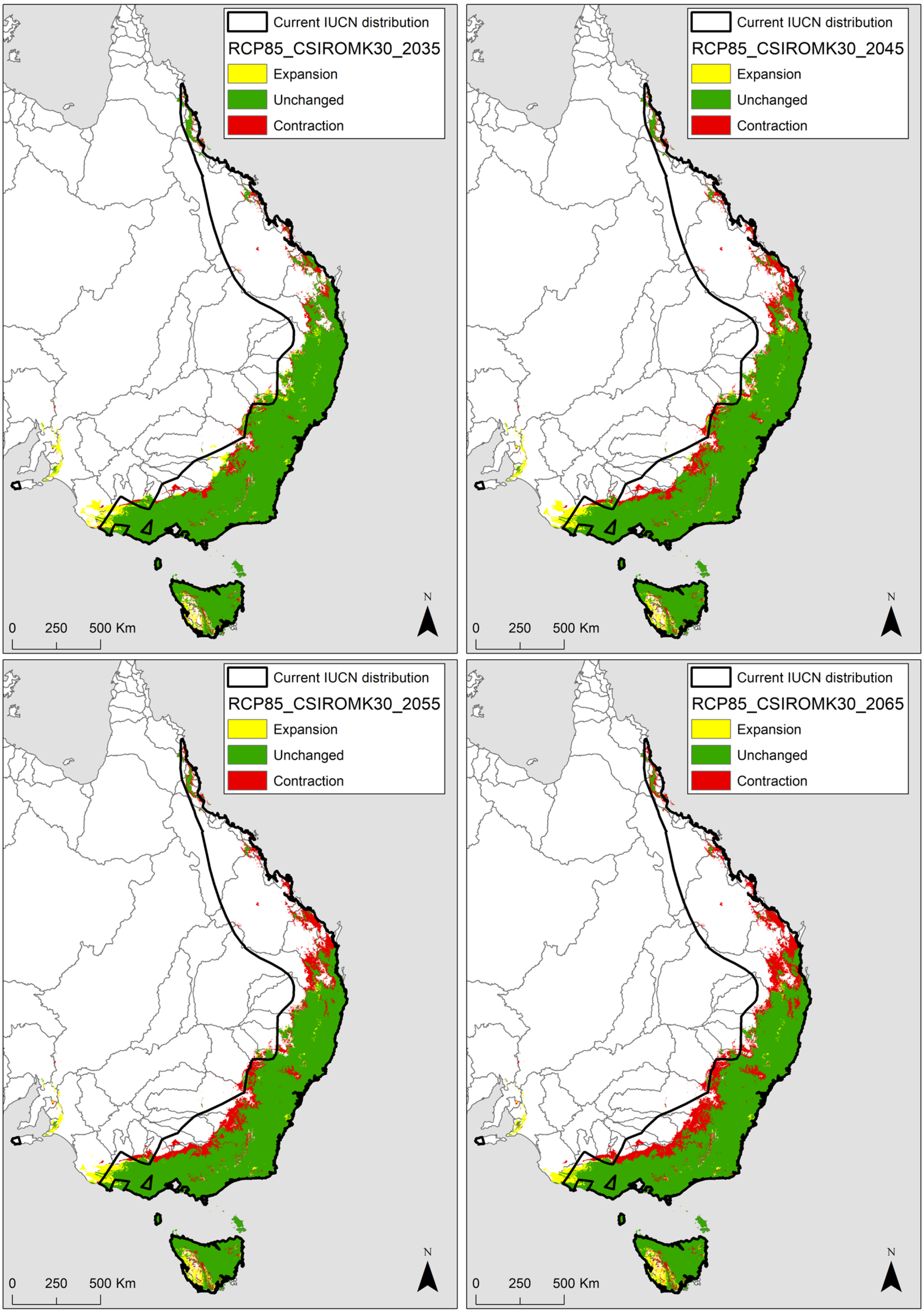


Figure 23 Change in estimated climatically suitable area of under RCP 8.5 GCM Mk3 climate change scenarios between 2035-2065

Cease to flow and drought

Drought can cause rivers and creeks to reduce flows or cease flowing completely. Extended periods of drought which dry up rivers and creeks reduces available habitat for platypuses, decreasing foraging ability and increasing competition (Bino et al. 2019). This may force platypuses to move overland to disperse to refuge pools, where they become particularly vulnerable to predation by foxes and dogs (Grant & Fanning 2007).

Cease to flow duration has been shown to be significantly related to platypus abundance in the Melbourne region (Mitrovski 2008; Griffiths et al. 2019). Across the distribution of the platypus, river cease to flow days have been increasing in 85% of sub-catchments with available data (Figure 24). Current climate change projections indicate an increase in both drought frequency and severity, which will continue to put pressure on platypus populations.

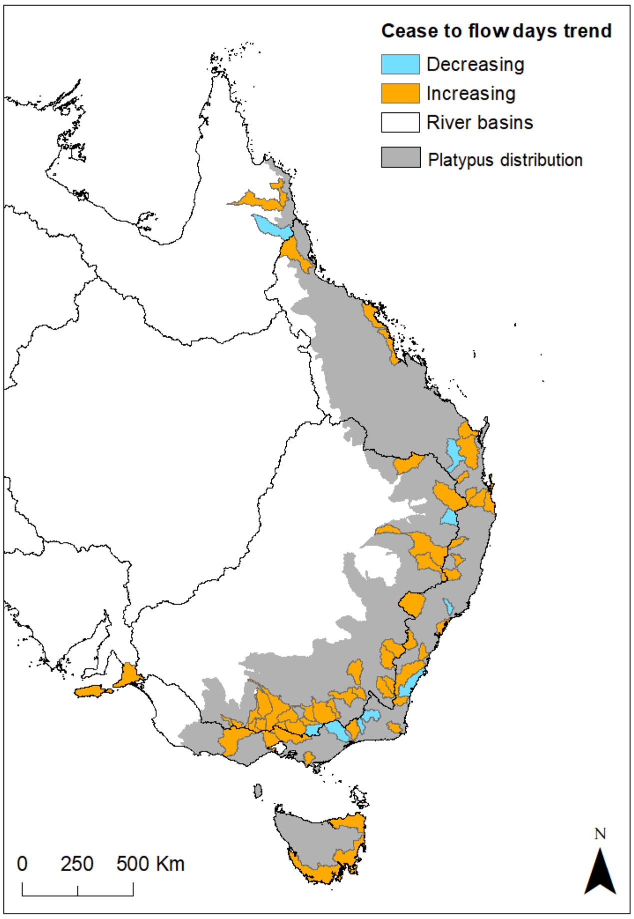


Figure 24. Trends in cease to flow days (Australian Bureau of Meteorology 2020) for sub-catchments with available data within the current IUCN distribution for platypuses, where increasing indicates more cease to flow days.

Bushfires

Increased severity and occurrence of bushfires is also likely to significantly impact platypus populations due to loss of riparian vegetation and reduced water quality, through deposition of ash and sediment into streams. Previous research suggests that fires which occurred in Gippsland (2006) (Serena & Williams 2008), western Victoria (Griffiths et al. 2015; Williams & Serena 2006), and near Melbourne (Bloink 2020; Armistead & Weeks 2009), had no impact on local platypus populations or their breeding. It is anticipated that in some areas, severe bushfires, in combination with drought and reduced water availability, will have a significant effect on platypuses.

The bushfires of 2019 and 2020 (Figure 25), which were preceded by a severe drought in many parts of the platypus' range, have likely significantly impacted platypus populations in some areas. The timing of the fires may have also increased their impact, given they coincided with juvenile emergence in some regions (Grant et al. 2004), but this was likely also confounded by the drought (Serena & Grant 2017). To estimate the extent to which platypuses were exposed to bushfires, we used the predicted probability of occurrence derived from developed habitat suitability model using recent data (1990-2020). Following examination of model accuracy, we removed probabilities lower than $P = 0.25$. We then summed probabilities (cell size 250 m × 250 m) across all Australian bioregions that intersected with the predicted platypus distribution. Within each bioregion, we then calculated the sum of probabilities that overlapped with the extent of the recent bushfires (Environmental Resources Information Network 2020) and calculated their proportion from the sum of probabilities across the entire bioregion. We estimated that 13.56% of available platypus habitat was impacted during the 2019-20 bushfires (van Eeden et al., 2020).

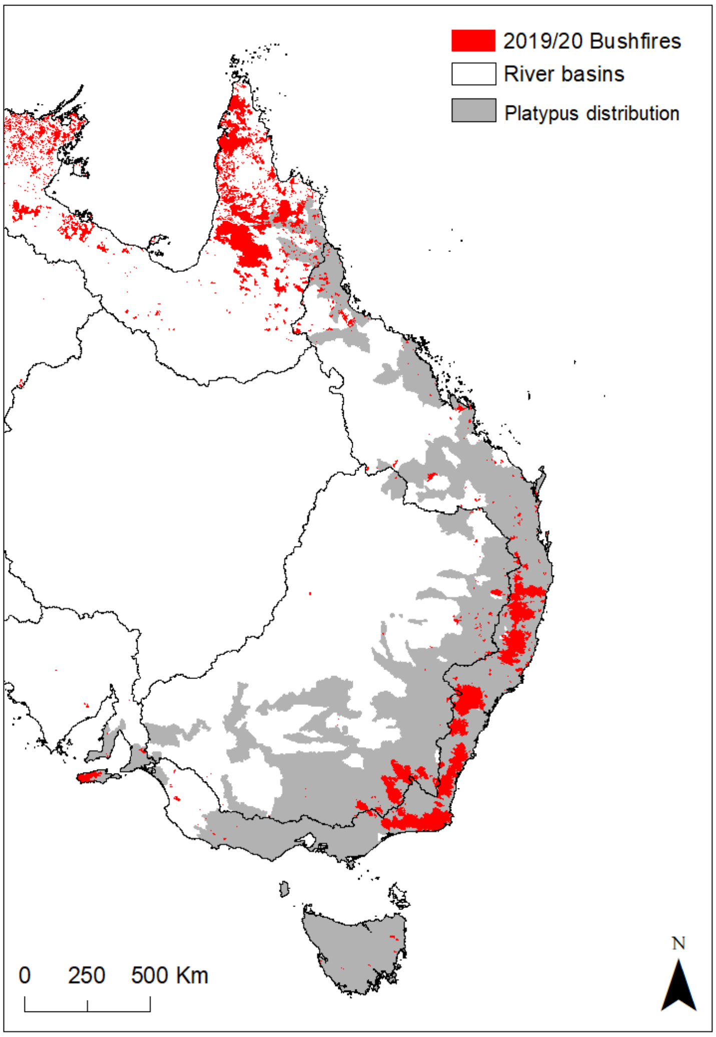


Figure 25. Extent of the 2019/20 bushfires (Australian Government 2020) across Australia and the current IUCN distribution for platypuses.

Case study: 2019/20 bushfires in the Mid-coast area

To assess potential impacts of bushfires on platypuses, we surveyed platypus populations in the Manning and Hastings River catchments (Figure 26). Creeks and rivers in the Manning River catchment (Dingo, Bulga, and Bobin Creeks) were impacted by recent bushfires, while those in the Hastings catchment (Thone River) were not burnt. We surveyed platypuses in August 2020, six months after the fires, over 11 night using mesh and fyke nets, dependent on river geomorphology. Four pairs of fyke nets (30 mm knotless 20 ply nylon, 1m x 5m wings and 0.8 x 5m wings) were used in small shallow streams (<1m), with one facing upstream and one facing downstream, spaced over a distance of 500 m. Fyke nets were set in the afternoon and checked every three hours until 8.00am. In larger pools (>1.5m deep), we used unweighted mesh nets. Mesh nets were set from dusk until midnight, and visually checked them every 2-3 minutes with a spotlight and removed platypuses and non-target species immediately. We also physically examined nets every hour to remove possible snags. We surveyed for macroinvertebrates using a 350 mm mesh sweep net (opening 33 x 26 cm) by holding the net opening upstream, flush with the substratum, and kicking and dislodging the substratum. We also measured water quality, taking pH, Dissolved Oxygen, Turbidity (ppm) and Conductivity (µm).

On a part of Dingo, Bulga, and Bobin Creeks, directly impacted by the fires, we trapped one platypus (male adult) when using Fyke nets, equating to 0.04 platypuses per Fyke night, and one platypus (female adult) when using a mesh net. On another downstream section of Dingo Creek, not directly impacted by the fire, we trapped three platypuses (two male and one female adult) when using mesh nets, equating to 1.5 platypuses per mesh net night. In comparison, on the unimpacted Thone River, we trapped three platypuses (two male adults, one recapture) when using Fyke nets (0.375 platypuses per Fyke net night or 0.250 not including recaptures) and four platypuses (two male adults, one female adult, and one unknown as it escaped from the net during retrieval) when using a mesh net (4 platypuses per mesh net night, or 3 not including recapture of the fourth platypus), (Figure 1). This suggests capture rates of platypuses were lower in the areas affected by the recent bushfires.

We assessed the SIGNAL score (Chessman 2003) of macroinvertebrate communities, with the Thone River having a slightly higher score (5.22), compared to part of Dingo Creek affected by fire (4.51). There were notable differences in the abundance of yabbies (Decapoda) and beetles (Coleptera), which were found in greater numbers on the Thone River compared to the fire impacted creeks. Dissolved oxygen differed between sites, generally decreasing with increased elevation, higher on the Thone River (n=3, average 65.1%) compared to part of Dingo Creek affected by fire (39.5%), and very low in Bulga Creek (17.8%). Turbidity and conductivity were somewhat lower on the Thone River (73NTU and 37mS/m) compared to Dingo Creek (87NTU and 43mS/m).

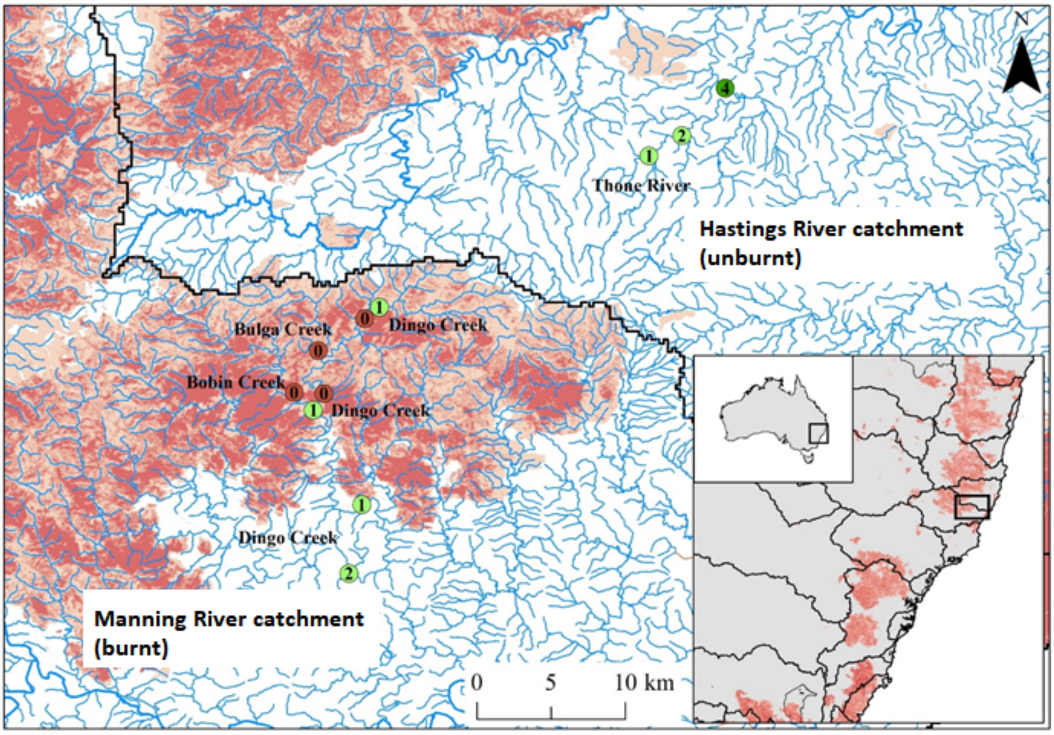


Figure 26. Location of capture sites and number of capture platypuses in the Manning and Hastings River catchments on the Mid-coast.

Conservation

Current knowledge gaps

Platypuses are difficult to survey in the wild due to their cryptic and nocturnal nature. These challenges impede accurate assessment of their distribution, abundance, and demographics that are essential for assessing the conservation status of the species. Between 1858-2020, platypuses were reported in 279 sub-catchments (855,099 km^2), (Figure 27a). There are 412 sub-catchments (1,103,410 km^2) within the current IUCN distribution for platypus (Figure 27b). Of these sub-catchments, 161 currently have no record of platypus (328,472 km^2), highlighting the knowledge gaps across the species' range. Additionally, there are sub-catchments outside the IUCN distribution which have platypus records, further highlighting the distributional knowledge gaps.

There is a need to incorporate the platypus into state and national monitoring programs aimed at improving current knowledge of platypus distribution and establishing critical baselines for future long-term monitoring.

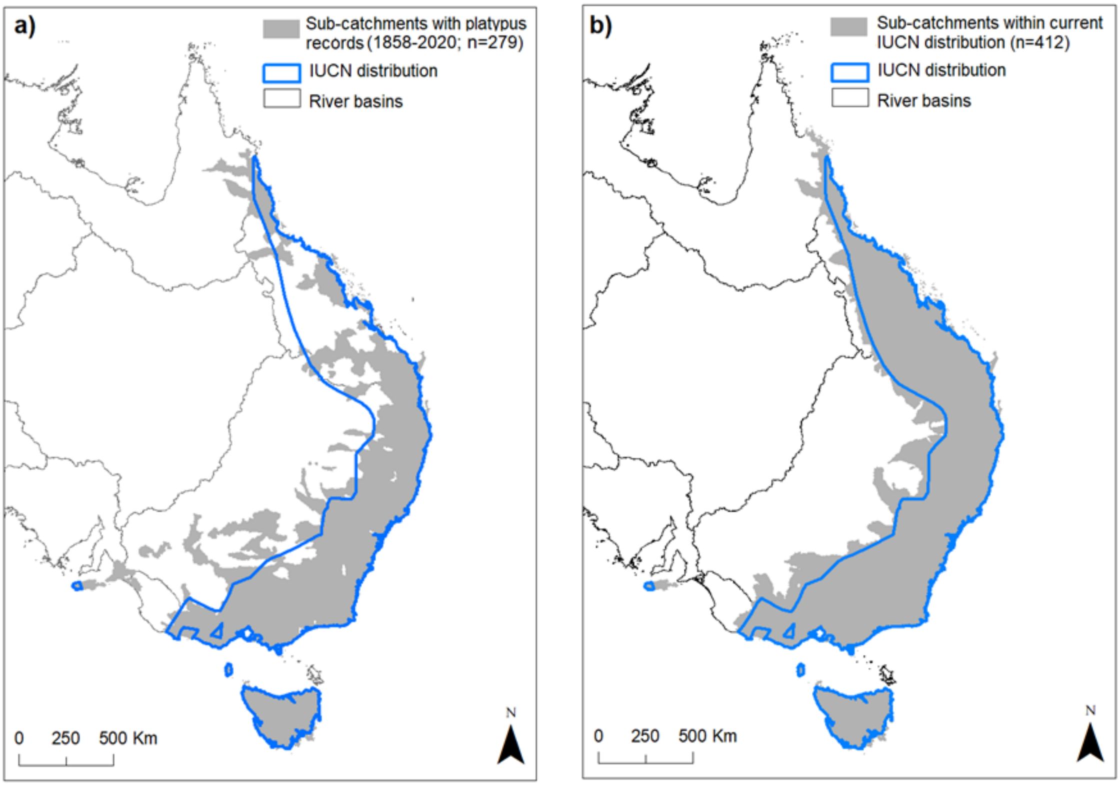


Figure 27. a) Sub-catchments with platypus records (1858-2020) and b) Sub-catchments intersecting with the current IUCN distribution for platypus (blue line).

Conservation actions in place (See Appendix for additional information)

Based on assessment of threats and evidence of localised declines, the platypus was listed as 'Near Threatened' in 2016 on the IUCN Red List of Threatened species (Woinarski & Burbidge 2016; Woinarski et al. 2014). The platypus is legally protected in all states where it occurs, but only listed in South Australia as Endangered (*National Parks and Wildlife Act 1972*) and was listed as Vulnerable in Victoria on 10th January 2021 (*Flora and Fauna Guarantee Act 1998*). Platypuses are not currently listed on the threatened species schedules of any other Australian state or nationally (i.e., *EPBC Act 1999*). The use of closed-topped freshwater crayfish traps, which frequently drown platypuses, are now totally prohibited in all waters in Tasmania, Victoria, and the ACT, but continue to be permitted in public waters outside platypus distribution in NSW and in specified still waters (lakes and reservoirs) within platypus distribution in QLD.

Monitoring actions in place

In 2019, the Australian Platypus Conservancy launched an online reporting system/app for community-based platypus visual monitoring at fixed sites over time (the Australian Platypus

Monitoring Network). Cesar Australia, in collaboration with the University of Melbourne, Monash University, and San Diego Zoo Global Conservancy, is currently undertaking widespread eDNA sampling of platypus habitat throughout the species' distribution to verify the current range. There are two Australia-wide online reporting methods that provide a mapping interface to report sightings (platypusSPOT and iNaturalist/Atlas of Living Australia), complemented by other state-based or regional wildlife reporting systems (e.g. Victorian Biodiversity Atlas, Canberra Nature Map).

Conservation actions needed (See Appendix for additional information)

Future surveys

The effective conservation of the platypus is reliant on systematic long-term monitoring of trends in distribution, abundances, demographics, health, and genetics. To effectively monitor these trends, a national monitoring program for platypuses should be established. Given the increasing support for research of charismatic species (Lunney 2012), the platypus has the potential to be a focus for citizen science monitoring. Widespread assessments of platypus distribution could be undertaken using eDNA, supported and complimented by citizen science wildlife surveys and monitoring initiatives which are also valuable as a strategy to increase appreciation of rivers and the natural environment by people. These studies should be undertaken in areas where there is uncertainty about the distribution of the platypus (Figure 1). However, such strategies are limited for quantifying population viability, only providing estimates of occurrence rather than condition, demographics (e.g., breeding) and population size which require more rigorous methods.

Dedicated programs with resources are needed to systematically assess population sizes, demographics, health, and genetics using mark-recapture surveys. Such assessments should be achieved by platypus-focused surveys but also by integrating platypuses into existing freshwater surveys (e.g., turtles and fish) and follow standardised marking and identification protocols. These programs need to target areas where there are potential concerns for threats as well as areas where there is poor data coverage.

Platypus-focused surveys also yield information other freshwater species also improve knowledge of the distribution of other freshwater species, including native and exotic fish species, and threatened species that coincide with the distribution of the platypus. eDNA surveys can be tailored for other freshwater species. Vice-versa, surveys being undertaken using either DNA sampling or capture sampling for other species than the platypus, should be encouraged to record platypus captures and undertake tagging to allow deriving estimates of abundances and trends as well as report these to atlas databases.

Mitigating threats

Reducing the extent and severity of threats is essential for the long-term survival of platypuses. There is urgent need for a national ban on enclosed yabby traps, following recent bans in Victoria and the ACT. Maintaining healthy riparian habitats is critical for platypuses, and land clearing needs to be prevented to maintain stable riverbanks for burrowing, and to provide organic material and shelter. Cattle grazing access should be limited in riparian vegetation areas, to reduce bank destruction and erosion. In already degraded riparian habitats, restoration through rehabilitation of riverbanks by replanting trees is essential for maintaining and improving platypus habitat requirements.

Building of more dams will likely contribute to further declines of platypuses, given changing flow regimes can impact their macroinvertebrate food sources, disrupt breeding, and reduce abundances downstream of dams. In-stream flow requirements and environmental flows need to be managed to maintain critical refugia and connectivity and water transfers and deliveries need to be improved to avoid detrimental impacts to the survival of platypuses and their food sources. This is particularly important in small streams, where platypus numbers are low and permanent drought refugia may not exist. Connectivity across regulated and fragmented rivers should be improved or maintained by limiting and removing in-stream barriers such as dams/weirs and developing "platypus-ways" to allow platypus movement across these barriers.

Research

While there is a need to improve the understanding of the distribution and abundance of platypuses, future research should also prioritise improving the understanding of how threatening processes are impacting individuals and population dynamics, including survival and dispersal. There is uncertainty regarding the timing, distances, and barriers of juvenile dispersal. Future use of novel genetic technologies can also offer significant insights into aspects of life history, as well are inferring the capacity of platypuses to adapt to climate change (Bino et al. 2019). Zoos play a vital role in platypus conservation by undertaking research, contributing to public awareness of threats, and establishing insurance populations to secure genetic diversity. The success of these captive breeding programs remains sporadic, suggesting more directed efforts are needed to understand the breeding requirements of platypuses. Future captive breeding populations may also allow for potential platypus re-introductions to areas which they historically inhabited.

Legislation

Conserving the platypus must become a priority at all levels of government, including listing on both state and federal threatened species schedules, particularly the Environment Protection and Biodiversity Conservation Act 1999.

Summary of declines

A. Population size reduction
In peri-urban Melbourne catchments where long-term capture data was available, platypus captures declined in four out of six catchments, with decline estimates ranging from 18% (95%CI: 4% - 40%) to as high as 65% (95%CI: 59% - 68%). In the Greater Brisbane region, surveys indicate disappearance of platypuses from 24% of waterways since 1990. Given declines in these peri-urban areas are derived from robust methods including capture data and eDNA sampling, confidence in estimates is high.
Population size reductions are also inferred from declines in platypus distribution. Declines in EOO are estimated to be 21.3% in the last three generations, highest in NSW (28.5%) and QLD (29.6%). For AOO, platypuses were detected in 2,350 grid cells in the 2000-2006 period, but only in 1,371 cells in the 2014-2020 period. Between the 2000-2006 and 2014-2020 time periods 8% of sub-catchments had a significantly lower number of platypus records in the latter period, representing a 10% decrease in the species' habitat quality.
Estimates of changes in EOO, AOO, and the number of records across time periods are predominantly reliant on atlas and opportunistic data with known spatiotemporal biases. While there can be shortcomings and biases which result from using these data for such analyses, we consider them indicative of changes and rely on them in the absence of widespread monitoring. We consider there estimates as having a medium level of confidence, which may be either lower or higher.
Based on metapopulation models, effective minimum population size was predicted to have declined between 45.0% and 58.1% under current climate and existing extent and severity of threats.
Under climate change projects, effective minimum population size is predicted to further decrease between 4.4% and 13% but likely higher given the species' climatic niche may contract between 17% to 43% by 2055.
B. Geographic range
The EOO for platypuses is estimated to be 747,521 km^2 within the last three generations. There is evidence for continuing declines in EOO, likely attributable to reduced habitat quality.
The AOO for platypuses for the last three generations is estimated to be between 16,440 km^2 (4,110 grid cells, lower bound) and 378,624 km^2 (94,656 grid cells, upper bound).
C. Small population size and decline
We estimate the number of mature individuals to be 186,847 - 336,325
D. Very small or restricted population
We estimate the number of mature individuals to be 186,847 - 336,325
E. Quantitative analysis:
Probability of extinction in the wild in the next three generations (21 years) is expected to be zero.

A. Population size reduction

Platypuses are threatened by a range of human activities since European settlement, associated with changes in land use and water extraction. In some areas, there is mounting evidence of both declines in distribution and abundance due to the synergistic impacts of threatening processes. Population reductions are also inferred from declines in the area of sub-catchments (21.3%) and rivers which platypuses occupy (21.1%) in the last 21 years, with declines almost reaching 30% in QLD (29.6%), NSW (28.5%) and the Murray Darling Basin (27.9%). In peri-urban areas, populations of platypuses across the greater Melbourne region have been estimated to decline between 18-65% (1995-2019). Between the 2000-06 and the 2014-20 time-periods, there has been a 10% decrease in the proportion of habitat where platypuses were reported. Significant declines are inferred from synergistic threats across the distribution of the platypus, reducing habitat quality and increasing fragmentation. Population viability analyses predict a historical decline in effective minimum population sizes between 45.0% and 58.1% as a result of existing impacts of land clearing, river regulation, and extreme drought. As examined threatening processes (i.e., land clearing and water resource development) began more than 50 years ago but have remained at high rates, we assumed most declines have likely occurred but continue. Given that the causes for these declines have not ceased, and will likely continue, and are not reversible in the foreseeable future, the proposed assessment of the platypus is **Vulnerable** under criterion **A2**.

Continued population reduction of platypuses is also projected in the future, based on threats and the impacts of climate change on rivers. Assuming an increased frequency and duration of droughts, combined with fragmentation and habitat destruction, effective minimum population was estimated to further decrease between 4.4% and 13% but is likely higher given the species' climatic niche may contract between 17% to 43% by 2055. Given projected population size reductions result from threats which have not ceased and are not reversible, we suggest that the platypus should be assessed as **Vulnerable** under criterion **A3** and **A4.**

B. Geographic range

The estimated AOO of platypuses within the last three generations ranges between 16,440 km^2-378,624 km^2, assessing it as **Least Concern** under criterion **B**.

C. Small population size and decline

The platypus has an estimated large population size, exceeding 10,000 individuals, which assesses it as **Least Concern** under criterion **C**.

D. Very small population size and decline

The platypus has an estimated large population size, exceeding 10,000 individuals, which assesses is as **Least Concern** under criterion **C**.

E. Quantitative analysis

Probability of extinction in the wild in the next three generations (21 years) is expected to be zero.

Potential listing category

Assessment of risk of extinction is based on the criteria one or more of the highest risk categories. The platypus occupies an extensive range across eastern Australia, with an estimated large population size, assessing it as Least Concern under criteria B, C, and D. However, there is evidence for declines, which are projected to increase in the future, resulting from a range of threatening processes. Therefore, under criteria A (population size reduction), a listing of **Vulnerable** is justified.

			a	b	c	d	e
[X] A. Population size reduction	[ ] A1	*Based on any of the following:*	[ ]	[ ]	[ ]	[ ]	[ ]
	[X] A2		[ ]	[ ]	[X]	[ ]	[ ]
	[X] A3		[ ]	[X]	[X]	[ ]	[ ]
	[X] A4		[ ]	[X]	[X]	[ ]	[ ]
[ ] B. Geographic range	[ ] B1	*AND at least 2 of the following*	[ ]	[ ]	[ ]		
	[ ] B2		[ ]	[ ]	[ ]		
[ ] C. Small population size	[ ] Estimate number of mature individuals *AND one of the following:*	[ ] C1					
		[ ] C2 *AND:*	[ ] a: [ ] i, [ ] ii	[ ] b			
[ ] D. Very small populations	[ ] D						
	[ ] D2						
[ ] E. Quantitative analysis							

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Appendix

Appendix 1

Supporting classification schemes (v3.1) for IUCN Red list Assessment

https://www.iucnredlist.org/resources/classification-schemes

IUCN – CMP Unified Classification of Direct Threats & Stresses

Threat	Timing	Scope	Severity	Impact Score
1. Residential & Commercial development 1.1 Housing & urban areas	Ongoing	Minority (<50%)	Slow (<20%)	5
Stresses: 1. Ecosystem stresses > 1.1 Ecosystem conversion & 1.2 Ecosystem degradation				
2. Agriculture and Aquaculture 2.3 Livestock farming & ranching	Ongoing	Majority (50-90%)	Slow (<20%)	6
Stresses: 1. Ecosystem stresses > 1.1 Ecosystem conversion & 1.2 Ecosystem degradation				
5. Biological Resource Use 5.1 Hunting & collection 5.1.1 Intentional use	Past – unlikely to return	Minority (<50%)	Rapid (20-30%)	
Stresses: 2. Species stresses > 2.1 Species Mortality				

7. Natural System Modifications 7.1 Fire & fire suppression 7.1.3 Increase in Fire > bushfires	 Ongoing	 Unknown	 Unknown	
7.2 Dams & Water management/use 7.2.1 Abstraction of surface water 7.2.3 Abstraction of surface water 7.2.3 Abstraction of surface water 7.2.10 Dams & Water management	Ongoing	Majority (50-90%)	Slow (<20%)	6
Stresses: 1. Ecosystem stresses > 1.1 Ecosystem conversion & 1.2 Ecosystem degradation				
8. Invasive & other problematic species, Genes & Diseases 8.1 Invasive Non-native/Alien species/Diseases 8.1.2 Named species > Red fox (*Vulpes vulpes*), Feral cats (*Felis catus*), Wild dogs (*Canis familiaris*)	Ongoing	Majority (50-90%)	Slow (<20%)	6
8.1.2 Named species > Mucormycosis disease	Ongoing	Minority (<50%)	Slow (<20%)	5
Stresses: 2. Species stresses > 2.1 Species Mortality & 2.2 Species Disturbance				
9. Pollution 9.1 Domestic & Urban wastewater 9.1.3 Type unknown/unrecorded 9.2 Industry & Military effluents 9.2.3 Type unknown/unrecorded 9.3 Agricultural & Forestry effluents 9.3.4 Type unknown/unrecorded 9.4 Garbage & Solid waste > fishing line/plastics	Ongoing	Majority (50-90%)	Slow (<20%)	6
Stresses: 1. Ecosystem stresses > 1.2 Ecosystem degradation 2. Species stresses > 2.1 Species Mortality				
11. Climate change & Severe weather 11.2 Droughts > drying of rivers	Ongoing	Whole (>90%)	Rapid (20-30%)	8

11.3 Temperature extremes > heatwaves 11.4 Storms and flooding > flooding				
Stresses: 1. Ecosystem stresses > 1.2 Ecosystem degradation 2. Species stresses > 2.1 Species Mortality				

IUCN Habitats Classification Scheme

Habitat	Season	Suitability	Major Importance
5. Wetlands (inland)			
5.1 Permanent Rivers, Streams, Creeks	Resident	Suitable	Yes
5.5 Permanent Freshwater Lakes	Resident	Marginal	No

IUCN – Classification of Conservation Actions In-place

Monitoring and planning
1. Is there an action recovery plan? No
2. Is there a systematic monitoring scheme? No
Land/Water Protection & Management
3. Have conservation sites been identified? Yes
4. Does the taxon occur in at least one protected area? Yes
4.1 If yes, indicate what proportion of the population is within Protected Areas (1-100%) <30%
5. Is there an area-based region management plan? Yes
6. Is there invasive species control or prevention? Yes
Species Management
7. Is there a harvest management plan? No
8. Has the taxon been successfully reintroduced or introduced benignly? Yes
9. Is the taxon subject to ex-situ conservation? Yes
Education & Legislation
10. Is the taxon the subject of any recent education or awareness programmes? Yes
11. Is the taxon included in international legislation? No
12. Is the taxon subject to any international management/trade controls? No

IUCN – CMP Unified Classification of Conservation Actions Needed

1. Land/water protection 1.2 Resource & habitat protection > instream flow rights
2. Land/water Management 2.1 Site/area management > maintenance of riparian habitats 2.2 Invasive species/Problematic species control > Feral cats, foxes, wild dogs 2.3 Habitat and Natural Processes Restoration > riparian vegetation restoration, improved flow regimes
3. Species Management
3.2 Species Recovery
4. Education & Awareness
4.2 Training > improving citizen science identification and monitoring

Appendix 2

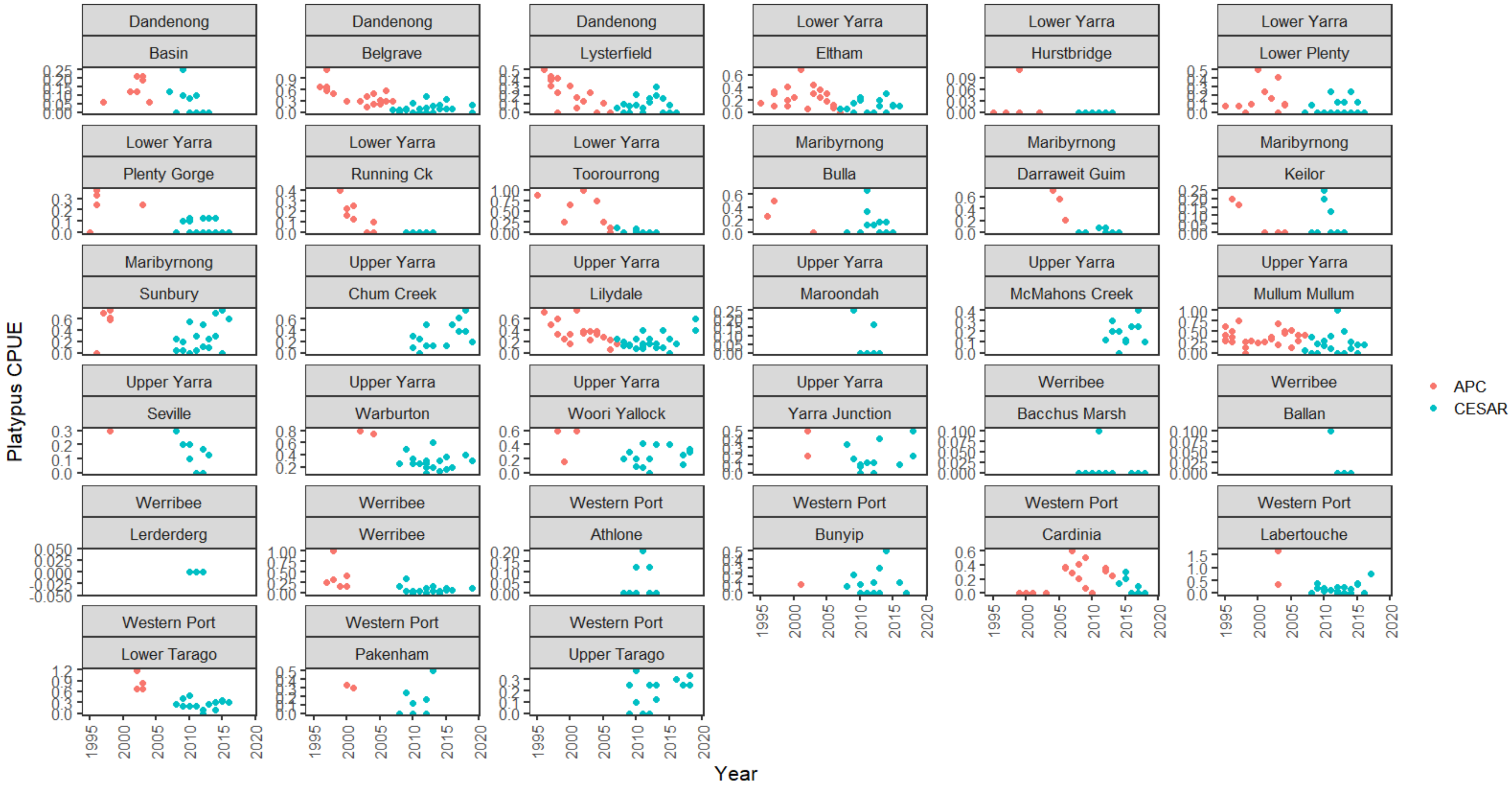

Figure 28. Platypus surveys (catch per unit effort (CPUE)) across the 33 sites in six basins in the greater Melbourne region between 1995-2019, coloured by organisation conducting the surveys (Australian Platypus Conservancy, Cesar Australia).

Table 12 Summary of modelled platypus numbers using generalized linear mixed model.

Note that the model does not consider environmental variables which limits separating between possible effects of organisation and environmental change during the two survey periods.

Predictors	Log-Mean	SE	p
(Intercept)	-2.76	0.31	**<0.001**
poly(Year, 2)1	-2.58	2.15	0.230
poly(Year, 2)2	8.08	1.63	**<0.001**
Catchment Lower Yarra	-0.36	0.39	0.361
Catchment Maribyrnong	0.53	0.41	0.195
Catchment Upper Yarra	0.85	0.35	**0.015**
Catchment Werribee	-0.59	0.49	0.232
Catchment Western Port	0.93	0.37	**0.012**
Organisation CESAR	-0.90	0.13	**<0.001**
poly(Year, 2)1:CatchmentLower Yarra	-5.15	3.65	0.158
poly(Year, 2)2:CatchmentLower Yarra	-9.98	2.99	**0.001**
poly(Year, 2)1:CatchmentMaribyrnong	6.46	2.99	**0.031**
poly(Year, 2)2:CatchmentMaribyrnong	2.52	3.22	0.432
poly(Year, 2)1:CatchmentUpper Yarra	8.11	2.17	**<0.001**
poly(Year, 2)2:CatchmentUpper Yarra	-3.83	1.89	**0.043**
poly(Year, 2)1:CatchmentWerribee	-7.45	3.80	**0.050**
poly(Year, 2)2:CatchmentWerribee	-2.07	5.04	0.681
poly(Year, 2)1:CatchmentWestern Port	-0.63	3.58	0.861
poly(Year, 2)2:CatchmentWestern Port	-3.79	3.31	0.253
Random Effects			
σ^2	0.54		
$\tau_{00\ Core\_site}$	0.24		
N_{Core_site}	33		
Observations	629		
Marginal R^2 / Conditional R^2	0.425 / 0.601		

Appendix 3

Platypus species distribution model summary 2000-2020 (7,409 records)

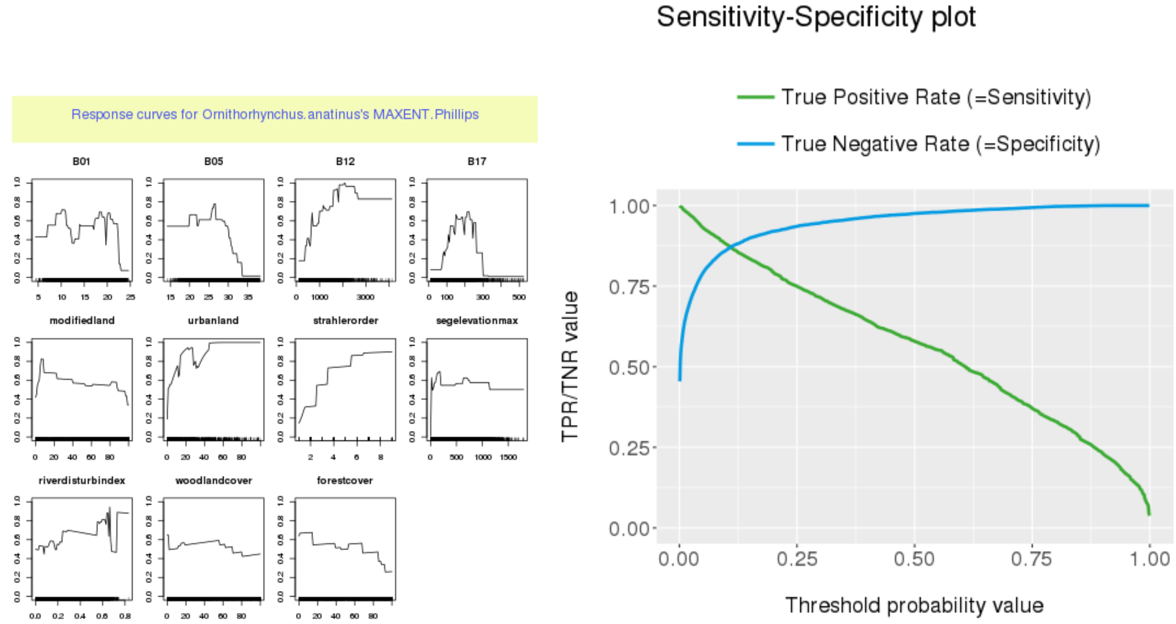

Figure 29 Response curves (left) and sensitivity-specificity plot (right)

Platypus species distribution model summary (1885-2020; 14,484 records)

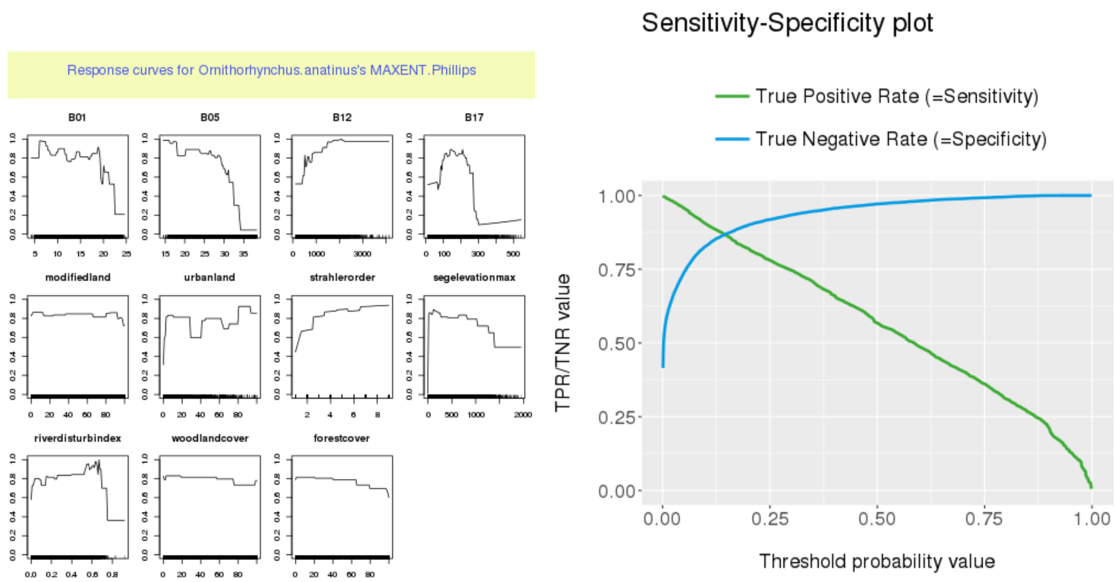

Figure 30 Response curves (left) and sensitivity-specificity plot (right)