Potential Implications of Sea Level Rise on Important Bird Areas, Victoria, Australia

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Anindita Roy

Department of Biological Sciences, Faculty of Science

Macquarie University, Sydney, Australia

The style and formatting of this thesis is written in the form of a journal article following the author guidelines of the Journal IBIS.

Declaration

I certify that all the research described in this thesis is my own original work.

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ANINDITA ROY

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ABSTRACT

Globally, a number of coastal localities have been classified as Important Bird Areas (IBA) as they contain favourable environments for feeding, breeding, nesting or stopover sites, and support a rich diversity of water birds. However, these habitats are vulnerable to inundation due to sea level rise (SLR). The state of Victoria, Australia, has 16 coastal IBAs, which contain saltmarshes, mangroves and intertidal flats that support a variety of resident and migratory birds. We assessed the potential inundation of these regions under SLR scenarios projected for this century. We used inundation layers, previously developed using a bathtub model, which projected SLR of 0.2m, 0.46m and 0.82m for 2040, 2070 and 2100, respectively. IBA and habitat shapefiles were overlaid with each scenario to calculate the area of each IBA and habitat type projected to be lost under the SLR scenarios. On average, 27% (sd ± 24%) of the area of IBAs is projected to be inundated with a 20 cm SLR, with this value rising to 40% (sd ± 28%) under the 82 cm scenario. Within IBAs, saltmarsh and intertidal flats may face substantial inundation, with an average loss of 46% (sd ± 33%) and 45% (sd ± 33%), respectively, under the 20 cm scenario. IBAs important for the critically endangered Orange Bellied Parrot and endangered Austral Bittern were projected to have the greatest exposure to inundation. Although all 16 IBAs have some land designated as protected, few have management strategies that explicitly account for SLR. Given the importance of these areas for birds, high resolution models of inundation that incorporate geomorphological characteristics of associated estuaries would greatly assist with identifying risks and designing appropriate adaptation strategies.

Keywords: Climate change, coastal habitat, important bird areas, inundation, sea level rise.

INTRODUCTION

Across the globe, coastal habitat is being altered due to land-use changes (e.g., urbanization) and, increasingly, climate change. Sea level rise (SLR) and increasing storm frequency resulting from climate change are the main factors predicted to affect coastal ecosystems (Murdukhayeva *et al.* 2013, Clausen & Clausen 2014). Understanding the potential magnitude of climate change and SLR is critical for effective conservation and management of coastal biodiversity (Veloz *et al.* 2013).

Trends and projections for temperature and SLR

From 1880-2012, globally averaged land and sea surface temperature increased by 0.85 °C (Stocker *et al.* 2013). Temperature is projected to rise a further ~ 0.3-0.7 °C over the period 2016-2035, compared to the baseline period of 1986-2005 (Church *et al.* 2013, Stocker *et al.* 2013). By 2100, mean annual surface temperature is likely to rise ~ 0.3-1.7 °C under the lowest emissions pathway (Representative Concentration Pathway 2.6 i.e., RCP2.6; 5-95th % range) to ~ 2.6-4.8 °C under the highest emissions pathway (RCP8.5), compared to 1986-2005 (Stocker *et al.* 2013). In the ocean, surface temperature is projected to increase 0.6-2.0 °C by 2100, depending on emissions pathways, while temperature at a depth of 1000 m may increase 0.3-0.6 °C (Stocker *et al.* 2013).

Latest estimates of global mean SLR suggest a rise of 1.2 mm/year (sd ± 0.2 mm/year) from 1901-1990, increasing to 3.0 mm/year (sd ± 0.7 mm/year) over the period 1993-2010 (Hay *et al.* 2015). Thermal expansion, melting of ice glaciers in Greenland and Antarctica and changes to land water storage are the main contributors to SLR, explaining 90% of the rise observed from 1971-2010 (Church *et al.* 2013). Projections indicate that by the end of this century SLR is likely to be 0.26-0.55 m under a low emissions pathway (RCP2.6; 5-95th% range) to 0.52-0.98 m under the highest emissions pathway (RCP8.5; 5-95th% range) (Church *et al.* 2013). However, there will be strong local and regional patterns in SLR, meaning that some areas may experience rates that differ to the above (Church *et al.* 2013). For instance, across Australia, interannual and decadal changes in climate and the movement of water are likely to lead to the southeast region undergoing SLR similar to global averages while higher rates may occur to the north of the continent (CSIRO & BoM 2014).

Impact of SLR on coastal habitats

Species and ecosystems in coastal areas are already responding to anthropogenic climate change and SLR; this is apparent in changes to species' distributions and phenology (Nicholls *et al.* 1999, Krauss *et al.* 2011, Brittain & Craft 2012). Among birds, coastal-dependent migrants are considered particularly vulnerable to habitat loss (Erwin *et al.* 2006, Mendoza-González *et al.* 2013). Wetlands, including saltmarsh and intertidal mud flats, provide key habitats for shorebirds and waterbirds, other animal species, and plants that may contribute to the stabilisation of sediment and creation of buffer protection between land and sea (Laegdsgaard 2006).

Waterbirds, many of which are trans-equatorial migrants, rely extensively on low lying tidal mudflats and saltmarshes for breeding, nesting and as stopover sites, as these habitats have high levels of primary productivity and form the base of estuarine food webs (Galbraith *et al.* 2002, Hughes 2004). However, such habitats are also at risk of inundation and fragmentation due to SLR (Galbraith *et al.* 2002, Hughes 2004, Clausen & Clausen 2014), particularly if they are unable to maintain elevation through vertical accretion (Traill *et al.* 2011). For example, marshlands along the Atlantic coast of the United States (USA) have been altered adversely due to SLR, storm and sedimentation processes, leading to the loss of a number of important shorebirds over the period 1947-1994 (Erwin *et al.* 2004). Similarly, shorebirds reliant on marsh areas along the Gulf of Mexico are under imminent threat from SLR (Woodrey *et al.* 2012), while in Florida, species such as Snowy Plovers (*Charadrius nivosus*) have declined 95% due to SLR-driven fragmentation and habitat loss (Chu-Agor *et al.* 2012). In Britain, the distributions of shorebirds have been affected by weather changes and habitat alterations due to SLR (Austin & Rehfisch 2003). Along the Netherlands' Wadden Sea coastline increasing intensity of summer floods (May – July) has eroded the breeding habitats of shorebirds (Van De Pol *et al.* 2010). Of the migratory birds using the East Asian-Australasian flyway, shorebirds are considered the most vulnerable to climate change and SLR (Iwamura *et al.* 2014). The population size of ~ 40% of these species has declined due to SLR and urbanization (Iwamura *et al.* 2013, Iwamura *et al.* 2014).

Along some areas of coastline, habitats may be able to keep pace with SLR, such as those that can modify the sedimentation process (e.g. vertical accretion by mangroves) (Bouma *et al.* 2009) or can migrate landward (Rupp-Armstrong & Nicholls 2007), or due to the geomorphological characteristics of the shoreline or associated estuary (Masselink *et al.* 2014).

However, human interference (e.g. via agriculture, land-use changes, urbanisation or interruption to the sediment supply process) may result in 'coastal squeeze', restricting landward movement of habitats (Saintilan & Williams 1999, Austin & Rehfisch 2003, Krauss et al. 2011). This may increase the loss of intertidal habitat (Rupp-Armstrong & Nicholls 2007, Clausen *et al.* 2013). For instance, it is estimated that by 2100, ~ 20-70% of intertidal habitat with steep topography situated along the Atlantic coast of North America may be lost due to a combination of SLR and urban barriers preventing landward migration (Galbraith *et al.* 2002).

Important Bird and Biodiversity Areas (IBAs)

Protected areas form the cornerstone for the conservation of biodiversity (Hannah *et al*. 2007, Lockwood *et al.* 2012). However, many areas important for birds and biodiversity have not formally been included in national protected area schemes (Dutson *et al.* 2009). BirdLife International, the primary conservation organization for avian species, has identified ~ 12,000 sites across the world as "Important Bird and Biodiversity Areas" (IBA), based on internationally agreed criteria (BirdLife International 2014). These include that the area has a significant number of a globally threatened species (i.e. listed by IUCN as critically endangered, endangered or vulnerable; referred to as IBA Category A1), or the presence of 1% of the global population of a restricted-range species (IBA Category A2) or biome-restricted species (A3), or the presence of a major congregation of a species (A4).

One of the main goals of IBAs is the conservation of migratory and resident shorebirds, waders and waterbirds (Dutson *et al.* 2009). However, IBAs in coastal regions may be vulnerable to future climate change and, specifically, SLR. To date, there has been little research on the implications of SLR for birds and biodiversity within these IBAs.

Across Australia, 314 IBAs have been recognised, 16 of which are found along the coastline of the south-eastern state of Victoria (Dutson *et al*. 2009). Here, using previously developed projections of SLR inundation, I undertook a GIS analysis to assess the potential implications of SLR on these coastal IBAs and their habitats, across three time periods for this century (2040, 2070 and 2100). Specifically, I assessed:

1. The area of each IBA that may be inundated due to SLR projections for the three time periods, and

2. The area of key shore- and waterbird habitats that may be inundated under these SLR projections.

My findings will enable the identification of those IBAs at greatest risk of inundation to SLR and will serve as a pilot study for future projects spanning other Australian states.

MATERIALS AND METHODS

Study sites

Along Victoria's ~ 2000 km of coastline (McInnes *et al.* 2013), 16 IBAs have been identified that are important for numerous migratory and resident waterbird species (Figure 1, Table 1) (Duston *et al*. 2009, BirdLife International 2015a-p). These include species classified by the IUCN as Least Concern (Chestnut Teal [*Anas castanea*], Pied Oystercatcher [*Haematopus longirostris*]), Vulnerable (Hooded Plover [*Thinornis rubricollis*], Far Eastern Curlew [*Numenius madagascariensis*]) and Critically Endangered (Orange-bellied Parrot [*Neophema chrysogaster*]) (BirdLife International 2015a-p). In addition, five of the IBAs contain wetlands that are listed under the Ramsar Convention, 2002: Corner Inlet, Gippsland Lake, Port Phillip and Bellarine Peninsula, and Western Port (Resources & Environment 2002a,b, Victoria 2003).

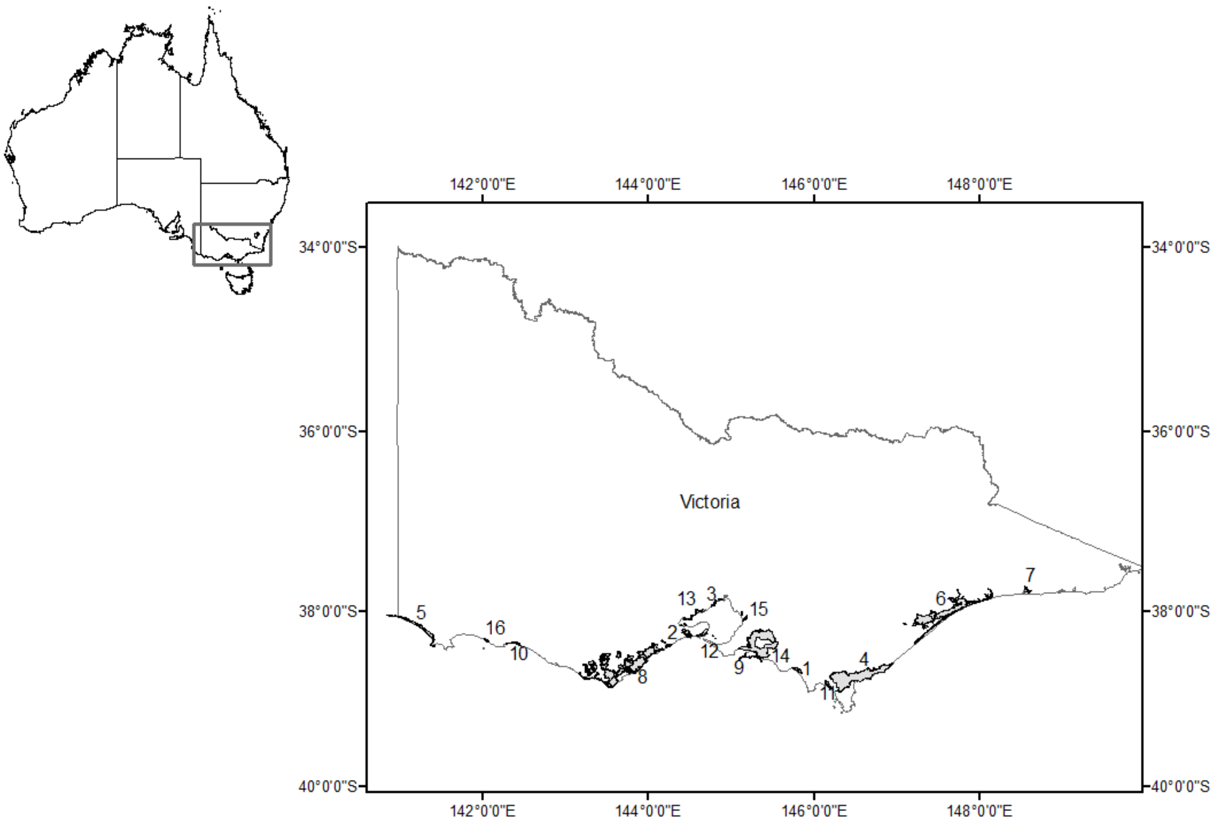

Figure 1. Coastal Important Bird and Biodiversity Areas (IBA) in Victoria. See Table 1 for the name of the IBA corresponding to the number on the map.

Table 1. The list of the 16 Important Bird and Biodiversity Areas (IBA) included in this study and type of birds supported.

IBA No	*IBA Name*	*IBA Bird Types*
1	Anderson Inlet	Migratory Shorebirds
2	Bellarine Wetlands	Resident Waterbirds, Migratory Shorebirds
3	Cheetham & Altona	Resident Waterbirds, Migratory Shorebirds
4	Corner Inlet	Resident Waterbirds, Migratory Shorebirds
5	Discovery Bay to Piccaninnie Ponds	Resident Waterbirds
6	Gippsland Lakes	Resident Waterbirds
7	Lower Brodribb River	Resident Waterbirds
8	Otway Range	Threatened Woodland Birds
9	Phillip Island	Resident Waterbirds, Seabirds
10	Port Fairy to Warrnambool	Resident Waterbirds
11	Shallow Inlet	Migratory Shorebirds
12	Swan Bay & Port Phillip Bay Islands	Resident Waterbirds, Migratory Shorebirds
13	Werribee & Avalon	Resident Waterbirds, Migratory Shorebirds
14	Western Port	Resident Waterbirds, Migratory Shorebirds
15	Carrum Wetlands	Resident Waterbirds, Migratory Shorebirds
16	Yambuk	Resident Waterbirds, Migratory Shorebirds

I reviewed literature to identify characteristics of each IBA, such as geomorphology, habitat types, species present and key IBA species, current threats and extent of protected areas, and whether climate change and/or SLR had been accounted for in management plans (OzCoasts 2008, BirdLife International 2014, BirdLife International 2015a-p) (see Appendix 1 and Appendix 2 for details). Most IBAs in this study have an area between 9-100 km^2, except Otway Range (1036.7 km^2), Gippsland (598.8 km^2), and Corner Inlet (364.6 km^2), and are situated around a number of tide- and wave-dominated estuaries. Primary habitat types within the IBAs include saltmarsh and intertidal flats, shrubland, grasslands and sandy beaches. The IBAs have a number of common threats including non-native invasive species and disease, recreational activities, pollution, erosion, agricultural practice and grazing pressure (Resources & Environment 2002b, BirdLife International 2015a-p).

Data layers and analyses

I obtained ArcGIS shapefiles of a) inundation scenarios for Victoria (Lacey & Mount 2012, McInnes *et al.* 2013, Victorian Coastal Inundation Dataset 2014), b) IBAs (available at http://www.birdlife.org/datazone/site), and c) coastal habitats (Dyall *et. al.* 2004).

Inundation scenarios for the Victorian coastline were previously developed using a hydrodynamic model that determined tide height and extreme SLR probability for three time periods (2040, 2070 and 2100) compared to the baseline period 1966-2003 (Lacey & Mount 2012, McInnes *et al*. 2013). Key input for the hydrological model included a 1 m Digital Elevation Model (DEM) and 0.5 m contour (Lacey & Mount 2012). The projections for SLR, based on the IPCC's 4th Assessment Report (2007) A1FI scenario, were 20 cm, 47 cm and 82 cm for 2040, 2070 and 2100, respectively (Lacey & Mount 2012, McInnes *et al*. 2013). Using a 'bathtub' approach, McInnes *et al*. (2013) and Lacey & Mount (2012) developed geospatial data to identify areas that may potentially be inundated under these SLR scenarios. This approach is comparatively straightforward but makes the assumption that present-day geomorphological characteristics will remain the same in future (Poulter & Halpin 2008, Murdukhayeva *et al.* 2013) (e.g. sedimentation processes that increase barrier protection by minimizing marine flushing of the estuary and aid in the migration of coastal habitats are not included in bathtub models).

Coastal habitats, available from the Victorian Coastal Waterways Geomorphic Habitat Mapping project (Dyall *et. al.* 2004) were reclassified into four habitat groups: saltmarsh, intertidal flats, mangroves, and 'other' (which included geomorphological characteristics such as back barrier, central basin, channel, flood- and ebb-tide delta, fluvial (bay-head) delta, rocky reef, and tidal sand banks). My analyses focused on saltmarsh, intertidal flats and mangroves only. Habitat data for two IBAs, Carrum Wetlands and Yambuk, were unavailable.

All analyses were conducted in ArcGIS v10.3 (ESRI 2014). Initially, shapefiles were converted to an equal area grid (VICGRID94, EPSG: 3111). I then overlaid the IBA and habitat shapefiles with the previously-developed inundation layers and calculated the extent to which each IBA and habitat type were projected to be inundated under each SLR scenario (see Figure 2). This is the earliest approach to find out the inundation impacts on the IBAs by comparing the inundation and IBA layers. To visualize potential impacts, we created KML files of projected inundation for three IBAs (Bellarine Wetlands, Swan Bay & Port Phillip Bay, Shallow Inlet).

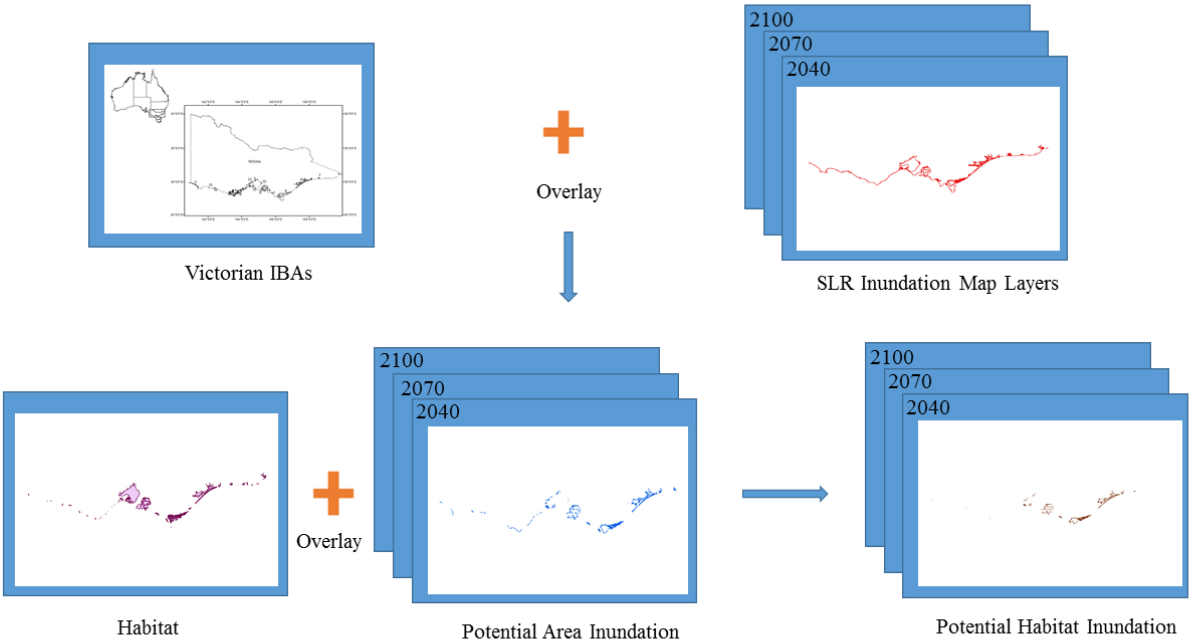

Figure 2: A schematic representation of the method use in this study to calculate the extent of IBAs and key habitat likely to be inundated under sea level rise scenarios projected for 2040, 2070, and 2100, relative to 2009.

RESULTS

Potential inundation of IBAs by sea level rise (SLR)

On average, 27% (sd ± 24%), 35% (sd ± 26%) and 40% (sd ± 28%) of the area of 16 coastal Victorian IBAs is likely to be inundated under SLR scenarios of 20 cm, 47 cm and 82 cm projected for 2040, 2070 and 2100, respectively (Table 2). However, the IBAs vary substantially in their exposure to SLR. Several are projected to have more than 50% of their land area inundated under the 20 cm scenario: Bellarine Wetlands (63.9%, covering an extent of 27.8 km^2), Lower Brodribb River (65.5%, 11.2 km^2), Shallow Inlet (54.2%, 9.7 km^2), Swan Bay & Port Phillip Bay Islands (63.4%, 5 km^2) (Table 2 and Fig. S1). In addition, > 50% of Cheetham & Altona (52.4, 3.5 km^2) and Western Port (54%, 34.5 km^2) is projected to be inundated with SLRs of 47 and 82 cm, respectively. Two IBAs, Anderson Inlet and Corner Inlet, may have between 30-50% of their total area inundated with a 20 cm SLR. For Corner Inlet, the third largest of the 16 IBAs, this amounts to ~110 km^2. The remaining IBAs are likely to have < 30% of their area inundated under the 82 cm scenario (2100), with Otway Range and Discovery Bay-Piccaninnie Ponds projected to have < 2% inundated.

Table 2. Area of Important Bird and Biodiversity Areas (IBA) projected to be inundated by 2040, 2070 and 2100, due to 0.2 m, 0.47 m, and 0.82 m sea level rise (SLR), respectively.

IBA no	IBA names	Total area (km^2)	Inundation					
			2040		2070		2100	
			Area (%)	Area (km^2)	Area (%)	Area (km^2)	Area (%)	Area (km^2)
1	Anderson Inlet	23.3	33.4	7.8	33.4	7.8	33.4	7.8
2	Bellarine Wetlands	43.6	63.9	27.8	82.2	35.8	91.6	39.9
3	Cheetham & Altona	10.4	33.7	3.5	52.4	5.4	69.1	7.2
4	Corner Inlet	364.6	30.3	110.6	34.7	126.4	38.8	141.6
5	Discovery Bay to Piccaninnie Ponds	90.8	1.2	1.1	1.5	1.4	1.8	1.7
6	Gippsland Lakes	598.8	13.7	82.2	17.2	103	19.3	115.4
7	Lower Brodribb River	17.1	65.5	11.2	73	12.5	76	13
8	Otway Range	1036.7	0.1	1	0.2	1.9	0.3	2.8
9	Phillip Island	15.7	5.2	0.8	5.7	0.9	6.5	1
10	Port Fairy to Warrnambool	13.4	3.9	0.5	22.1	3	33.9	4.5
11	Shallow Inlet	18	54.2	9.7	55.4	10	58.3	10.5
12	Swan Bay & Port Phillip Bay Islands	7.9	63.4	5	70	5.5	76.1	6
13	Werribee & Avalon	34.1	12.6	4.3	19.8	6.8	26.3	9
14	Western Port	63.7	28.6	18.2	38.8	24.7	54.2	34.5
15	Carrum Wetlands	9	8.4	0.8	13.7	1.2	19.4	1.7
16	Yambuk	9.3	12.7	1.2	33.9	3.1	39.9	3.7

Potential inundation of habitat

I assessed the extent to which key waterbird habitat within the fourteen IBAs for which data were available (i.e. all but Carrum Wetlands and Yambuk) is likely to be inundated under the three SLR scenarios (see Appendix 3 for details). On average, ~ 46% (sd ± 33%), 64% (sd ± 28%), and 75 % (sd ± 26%) of saltmarsh area within these IBAs was projected to be inundated by 2040, 2070 and 2100, respectively. Six IBAs (Bellarine Wetlands, Swan Bay & Port Phillip Bay Islands, Lower Brodribb River, Corner Inlet, Shallow Inlet and Anderson Inlet) were projected to lose more than 60% by 2040.

For intertidal flats, the average inundation was projected to be 45% (sd ± 33%), 52% (sd ± 35%), and 60% (sd ± 34%), for the three time periods, respectively. Port Fairy-Warrnambool was projected to lose all intertidal flats by 2040, while Werribee & Avalon may lose > 50% (Figure 3).

Mangroves are present in only five IBAs (Anderson Inlet, Bellarine Wetlands, Corner Inlet, Otway Range, Western Port): all except Otway Range are projected to lose > 60% of mangrove habitat by 2040 (Figure 3). Otway Range contains only a small fragment of mangrove (0.02 km^2), which is unlikely to be inundated by 2100.

SLR is likely to have the greatest impact on habitat in Corner Inlet and Bellarine Wetlands. Corner Inlet was projected to have 74% of both saltmarsh (41 km^2) and mangrove (11.2 km^2) habitat and 18% of intertidal flats (26.4 km^2) inundated by 2040. Nearly all saltmarsh in this IBA will likely be inundated by 2100, representing a loss of 47 km^2. Bellarine Wetlands was projected to lose 86% of the area of saltmarsh (9.2 km^2), 72.1% of intertidal flats (0.80 km^2) and 100% of mangroves (0.2 km^2) by 2040.

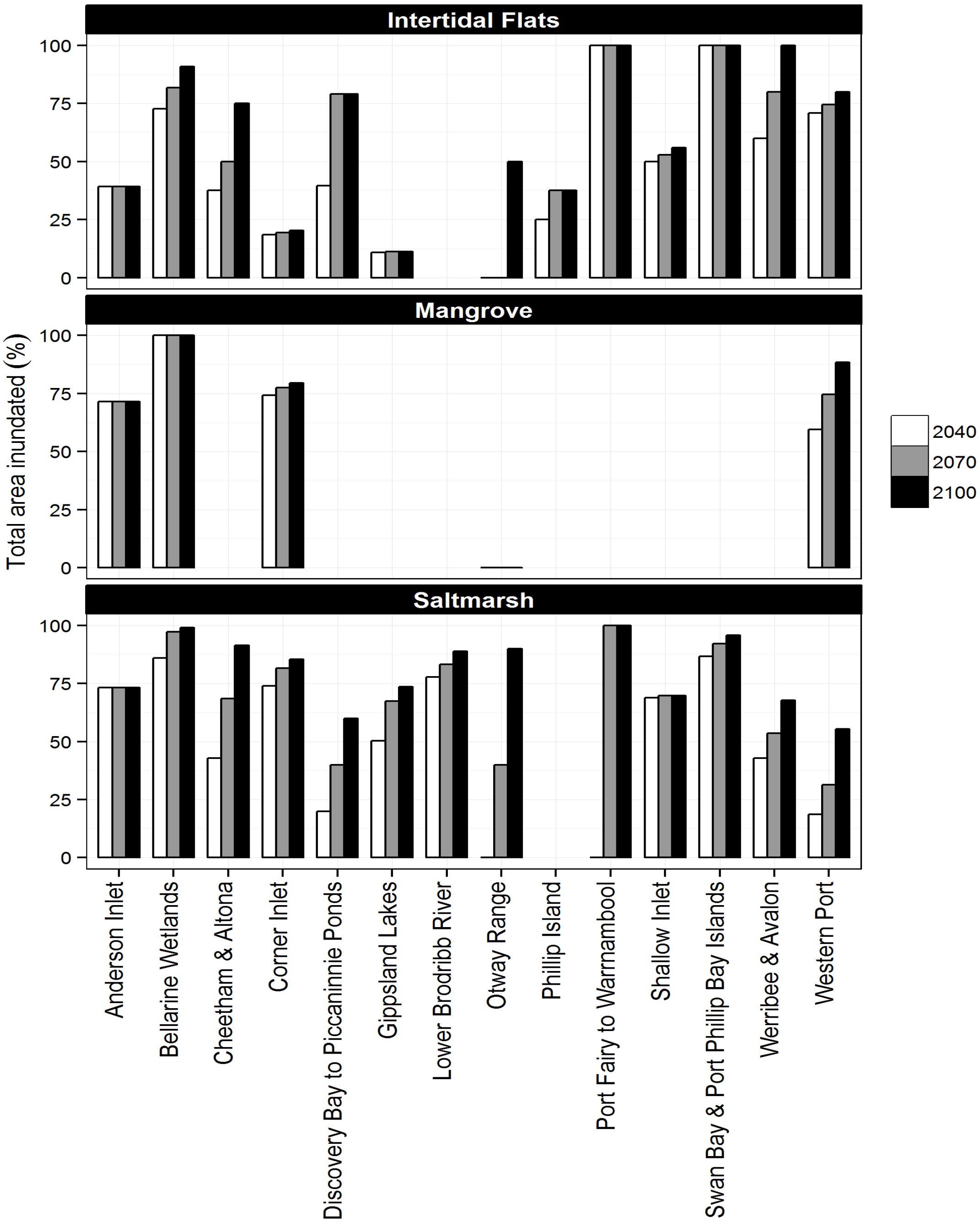

Figure 3: : Proportion of three habitat types within 14 Important Bird Areas (IBAs) in Victoria projected to be inundated due to sea level rise (SLR): saltmarsh (top panel); intertidal flats (middle panel); and mangroves (bottom panel). The IBA names are given in Table 2. Areal extent of projected inundation is given in Appendix 3.

I created KML files for three IBAs, which are connected with different types of estuary, to demonstrate inundation across the three time periods. Bellarine Wetland consists of fragments of wetlands connected to Port Phillip Bay (a tide dominated estuary) and Barwon River (wave dominated estuary). Saltmarsh, mangrove and intertidal flats currently found around Barwon River Estuary were projected to be inundated by 2100, if geomorphic conditions remain constant (Figure 4).

The Swan Bay & Port Phillip Bay Islands IBA contains a low altitude, tide dominated estuary with a large entrance. It is also connected with wave dominated estuary. This IBA was projected to lose almost all of its 5.5 km^2 of intertidal flats by 2100 (Figure 5).

Shallow Inlet contains a wave dominated estuary with a small entrance due to a sediment barrier. This is connected to the sea via a channel, and contains significant saltmarsh and intertidal flat habitat. Around 70% (7.3 km^2) of saltmarsh was projected to be inundated by 2040, a figure that increased only slightly by 2100 (7.4 km^2). Similarly, most of the loss of intertidal flats projected for this century will occur by 2040 (1.7 km^2 [52.6%], increasing to 1.8 km^2 by 2100) (Figure 6).

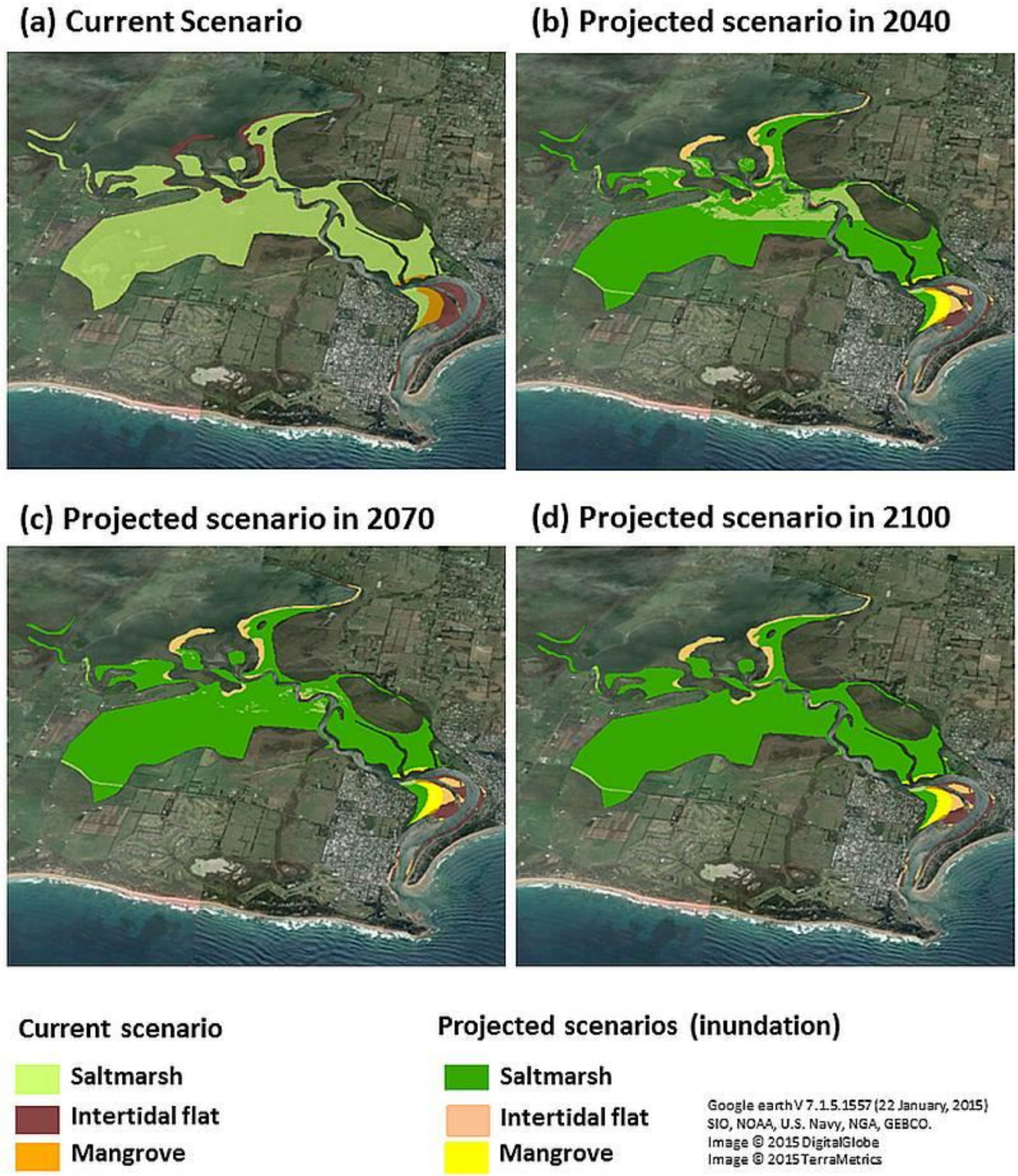

Figure 4: Projected inundation of key habitat within the Bellarine Wetlands IBA. (a) The current extent of saltmarsh (Lemon), intertidal flats (Brown) and mangrove (golden) habitat, and areas projected to be inundated due to sea level rise across three future scenarios: (b) 20 cm SLR (2040), (c) 47 cm SLR (2070), , and (d) 82 cm SLR (2100). The increase of inundation extent in saltmarsh, intertidal flat and mangrove has indicated by green, light orange and yellow.

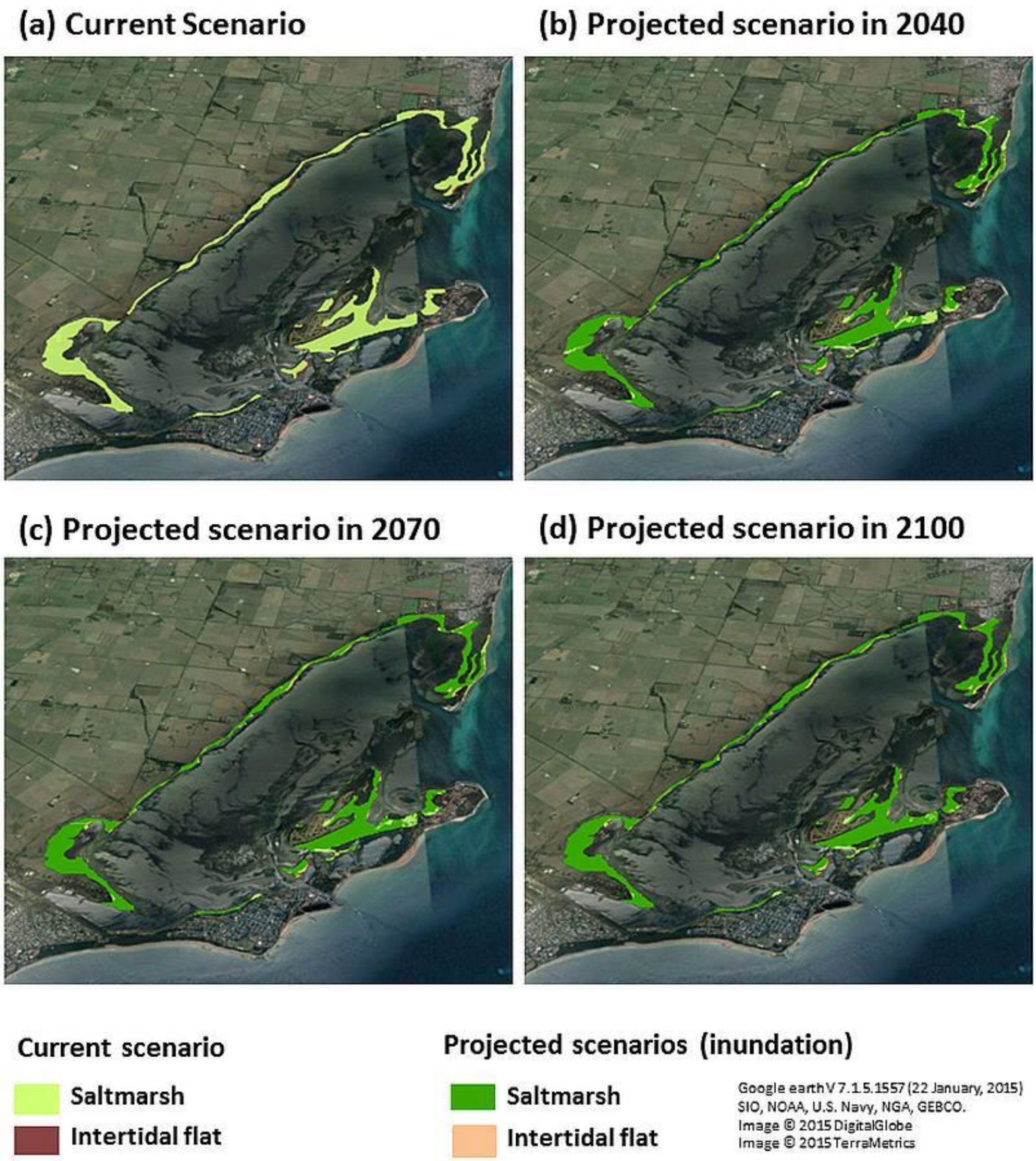

Figure 5: Projected inundation of key habitat within the Swan Bay and Port Phillip Bay Islands IBA. (a) The current extent of saltmarsh (Lemon), intertidal flats (Brown) habitat, and areas projected to be inundated due to sea level rise across three future scenarios: (b) 20 cm SLR (2040), (c) 47 cm SLR (2070), , and (d) 82 cm SLR (2100). The increase of inundation extent in saltmarsh, intertidal flat and mangrove has indicated by green, light orange.

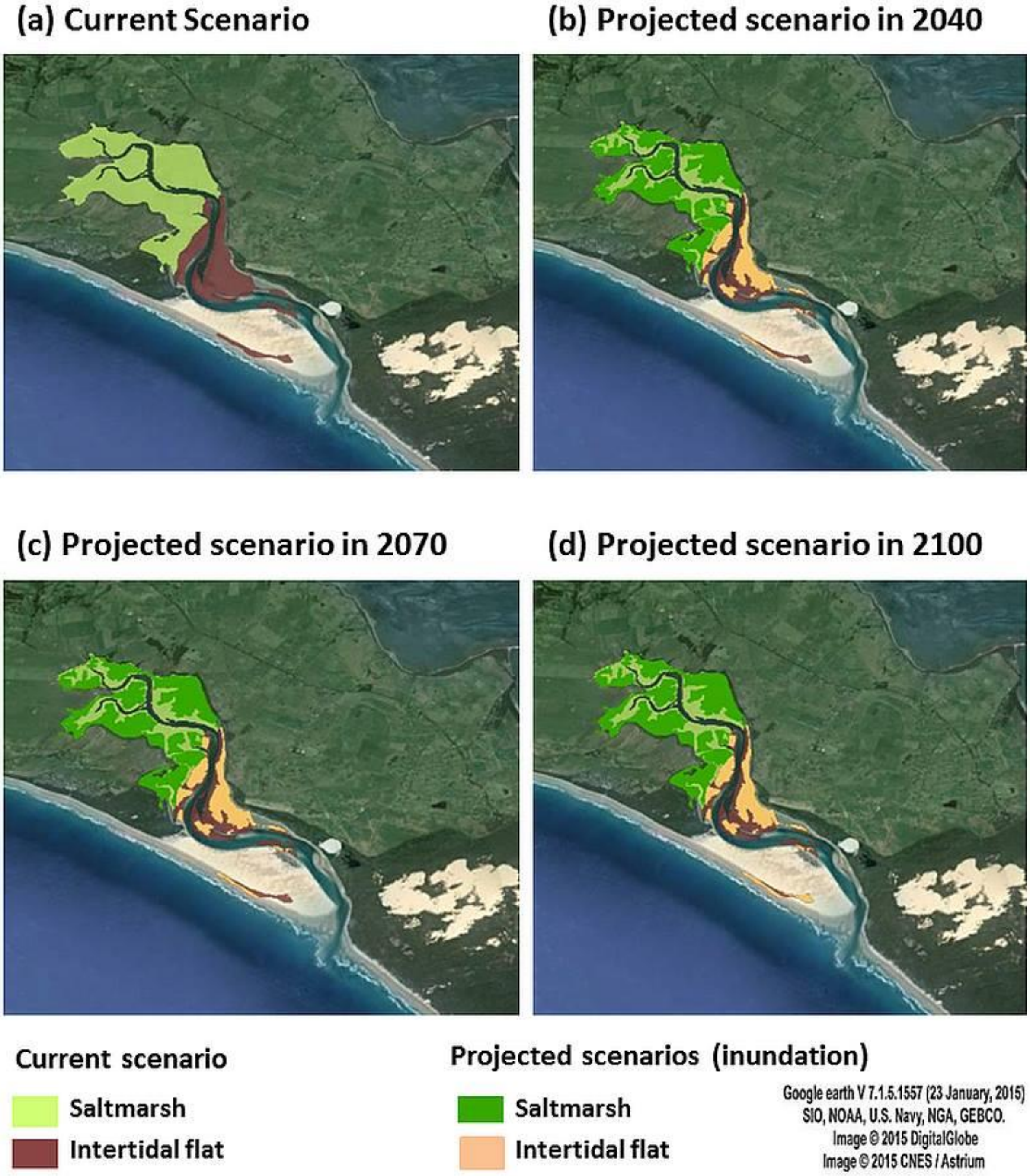

Figure 6: Projected inundation of key habitat within the Shallow Inlet IBA. (a) The current extent of saltmarsh (Lemon), intertidal flats (Brown) habitat, and areas projected to be inundated due to sea level rise across three future scenarios: (b) 20 cm SLR (2040), (c) 47 cm SLR (2070), , and (d) 82 cm SLR (2100). The increase of inundation extent in saltmarsh, intertidal flat and mangrove has indicated by green and light orange.

DISCUSSION

Sea level rise (SLR) is projected to inundate, on average, 27% (sd ± 24%) of the area of Victoria's 16 coastal Important Bird and Biodiversity Areas (IBA) by 2040, and 40% (sd ± 28%) by 2100. This represents an areal extent of 285 km^2 and 400 km^2, for the two time periods respectively. Given that these areas support globally significant numbers of birds, these results suggest that SLR may have substantial impacts on birds and biodiversity within coastal IBAs.

IBAs projected to lose the greatest total area are Corner Inlet (110 km^2 by 2040) and Gippsland Lakes (82 km^2 by 2040). Of these, Corner Inlet is particularly important for migratory and resident waterbirds, supporting significant numbers of several IUCN-trigger species as well as providing salt-marsh habitat for the critically endangered Orange-bellied Parrot (*Neophema chrysogaster*) (Appendix 1). In general, those IBAs that are less likely to be inundated by SLR have narrow intertidal zones with rapidly rising elevation, such as Otway Range. These areas contain relatively little saltmarsh, intertidal flats or mangrove habitat (Appendix 3) and are less important for shore and waterbirds compared with the other IBAs.

Projected inundation of key habitat for waterbirds

Intertidal mud flats, saltmarsh and mangroves provide key foraging sites for shorebirds (Laegdsgaard 2006, Rogers *et al.* 2006, Iwamura *et al*. 2013). Globally, saltmarsh and intertidal flats are the habitats most affected by SLR, and loss of these habitats may contribute to declines in shorebird abundance and diversity in the future (Galbraith *et al*. 2002, Hughes 2004, Granadeiro *et al*. 2007, Clausen *et al.* 2013). For example, across the Yellow Sea region of the East Asian-Australasian Flyway populations of 10 bird species were projected to decline up to 18% due to the loss of foraging habitat associated with a 50 cm SLR (Iwamura *et al*. 2014). A number of other studies have also assessed the effects of SLR on bird habitat, particularly on saltmarshes (e.g. Galbraith *et al*. 2002, Woodrey *et al*. 2012, Veloz *et al.* 2013). For instance, in the Georgia (USA) coastal area, SLR of 52 cm was projected to result in 20% loss of saltmarshes, little change (1% increase) to freshwater marshes, and an expansion of brackish marshes (19%) (Craft *et al.* 2008). Surface elevation table and accretion models indicated that the US Atlantic coastline may not keep pace with SLR and many areas may be below water level in the near future due to flooding: this may result in loss of nesting sites for many birds over the next 50-100 years (Erwin *et al.* 2006). However, to date few studies in Australia have been conducted on potential saltmarsh loss in spite of the significant richness and productivity of these habitats (Saintilan & Rogers 2009).

Across the 14 Victorian coastal IBAs for which habitat data were available, intertidal mud flats, saltmarsh and mangroves currently span 190 km^2, 175 km^2 and 29 km^2, respectively (although mangroves are present in only five of the IBAs). Corner Inlet includes a Ramsar site with extensive intertidal mudflats, spanning 143 km^2 and providing key food resources for 30,000 to 40,000 waders during the Austral summer (Resources & Environment 2002a). This IBA is projected to lose 18% of intertidal mud flats (26 km^2) by 2040, increasing slightly by 2100 (i.e. to 20% or 29 km^2). Given that most inundation of this habitat type is likely to occur within the next few decades, SLR should be incorporated into management plans for near future. Most of the remaining IBAs contain relatively smaller areas of intertidal flats (up to 5 km^2), although substantial portions of these may also be inundated by 2040 (e.g. Western Port 71%, 4 km^2).

Bellarine Wetlands, Shallow Inlet, Swan Bay & Port Phillip Bay Islands, Corner Inlet, Lower Brodribb River, and Anderson Inlet are all projected to lose more than 60% of saltmarsh (~ 65 km^2) by 2040, although this represents a relatively small areal extent for the latter two IBAs (< 1.5 km^2). From 2040 to 2100, loss of saltmarsh in Shallow Inlet remains stable (at ~ 69%), but increases to almost 100% in Bellarine Wetlands (10.6 km^2). Given that saltmarsh is the dominant habitat type in these two IBAs, this loss will have substantial impacts on the bird numbers that they can support. Furthermore, Bellarine Wetland, Swan Bay & Port Phillip Bay Islands and Cheetham & Altona IBAs are associated with the Ramsar site of Port Phillip Bay and Bellarine Peninsula, which currently supports more than 60,000 shorebirds over the Austral summer, and is also of importance for Orange-bellied Parrot (Victoria 2003). Combined, the three IBAs within this site are projected to lose 71.8% of saltmarsh (15.5 km^2).

Only five of Victoria's coastal IBAs contain mangroves: in four of those, 60% of mangrove habitat is expected to be inundated by 2040. Within Corner Inlet estuary, mangrove habitat has already declined due to SLR and erosion (Saintilan & Williams 1999, Saintilan & Rogers 2009). Further, SLR is a key driver of mangrove transgression into saltmarshes and has already resulted in declines in the extent of saltmarshes in southeast Australia (Saintilan & Williams 1999, Saintilan & Rogers 2009, Boon *et al.* 2011), including Western Port (Boon *et al.* 2010). If mangrove transgression continues, it may alter these projections of inundations (i.e. saltmarsh loss of 18.7% (4.7 km^2) and mangrove loss of 60% (7.5 km^2) by 2040).

Migration of habitats

Coastal ecosystems may have the ability to migrate, depending on geomorphological characteristics as well as sedimentation processes (Ryan 2003), and provided there are no physical barriers (Rupp-Armstrong & Nicholls 2007). Sediment trapping also influences changes to the shape and size of the estuary mouth and barrier formation (Ryan 2003) (see Appendix 5: Figure A2). For instance, wave dominated areas have the capacity to trap more sediment, which assists with the formation of an elongated narrower barrier in the estuary mouth and restricts the frequency of tidal flushing. Conversely, in tide dominated areas, the open estuary undergoes a high exchange of sea water through the estuary mouth: here intertidal habitat plays an important role in the sediment trapping process. However, more frequent tidal flushing causes fine sediment deposition and erosion to the intertidal mud flat (Ryan 2003).

Unfortunately, sedimentation rates were unavailable for the IBAs included in this study, making it difficult to determine the likelihood of habitat keeping pace with SLR. Generally, the high sediment deposition capacity of wave dominated areas (such as Shallow Inlet) may help them to keep pace with SLR. In contrast, the IBAs projected to face substantial inundation (e.g. Swan Bay & Port Phillip Bay Islands, Corner Inlet) are connected to tide dominated areas, and these areas may be unable to vertically accrete or shift landward (e.g., Shaugnessy *et al*. 2012).

Migration of coastal habitat also may not be possible in some areas due to coastal squeeze, which can result from activities such as urbanization, agriculture and other alterations to areas landward of coastal ecosystems (Rupp-Armstrong & Nicholls 2007). All 16 IBAs are currently being, or have recently been, subjected to habitat loss, the impacts of urbanization, invasive species, and modification of drainage systems. Corner Inlet has experienced major conversion of saltmarshes to pastures, with present saltmarshes bordered by channels and walls (Boon *et al.* 2011). Drainage and construction have also destroyed areas of saltmarsh in Western Port (Boon *et al.* 2011). The greatest loss of saltmarsh was projected to occur in Bellarine IBA by 2040 (86%). This IBA is situated on the Barwon River estuary and has little likelihood of migrating landward due to drainage patterns, urbanization, grazing and land use practices that limit the boundary of the estuary (Resources & Environment 2002b, Boon *et al.* 2011).

Urbanization, along with SLR, has been projected to impact coastal bird habitat in other areas of the world. For example, combined impacts of SLR and urban growth may reduce 59-64% of shrub habitat in Georgia, USA, by 2100, which may cause the loss of the highly vulnerable Painted Bunting (*Passerina ciris*) (Brittain & Craft 2012). It has been estimated that climate change has the capacity to affect 84% of populations of 298 migratory bird species that were listed in the Convention on the Conservation of Migratory Species of Wild Animals (CMS) 2003, while other anthropogenic impacts could affect 80% of those species (Robinson *et al.* 2009).

Limitations of modelling approach

There are a number of factors that have introduced uncertainty into this study, including a) the use of bathtub models to estimate inundation and resolution of models, b) estimates of SLR, c) inaccuracies in estimates of the extent of habitat types and d) other climate change impacts.

Different approaches exist to modelling SLR. This study utilised projections of inundation created from a bathtub model, which is a simple approach that does not consider how the shoreline may be altered by geomorphology and sediment supply. This may result in an under- or over-estimation of the area likely to be inundated by SLR. Due to the lack of the availability of robust morphodynamic models, the dimensions, tidal range and tidal prism that are likely to change in future could not be tailored in this study. Future studies using a variety of other models may provide more accurate results by incorporating coastal geomorphology behaviour and sedimentation processes, such as Bruun-GIS Model, Aggradation Model, Flood-Tide Delta Translation Model (Hennecke *et al.* 2004). However, these models are yet to be utilised to create inundation scenarios for the Victorian shoreline.

The hydrodynamic model used by Lacey and Mount (2012) to develop the inundation scenarios was based on 100 m to 1 km resolution and covers approximately 10 m in height above mean sea level. Further modelling at higher resolutions may allow the fine-scaled features such as drainage and water flow to be accounted for (Lacey & Mount 2012, McInnes *et al*. 2013).

An additional source of uncertainty regards the extent of SLR. Projections were derived from estimates of the 50% probability based on the IPCC AR4 report (2007) and A1FI scenario. This report suggested a SLR of 0.18-0.79 m over 1990-2095. Although globally averaged estimates, these are similar to the Victorian Coastal Strategy (2008), which projected that SLR will not be less than 0.8 m by 2100. Of concern, however, are recent suggestions that these rates may underestimate the magnitude of future rises (Hay *et al.* 2015).

Habitat inundation information was not available for two IBAs, and lack of precision in the spatial extent of the habitat shapefiles was apparent. Another error associated with the previously developed inundation model influenced the inundation result of Anderson Inlet (Figure 3). More up-to-date mapping of wetland areas along the Victorian coast would greatly assist with obtaining estimates of inundation. Further, this study was based on one aspect of climate change – sea level rise. Increasing temperature and changes to rainfall and runoff will also influence inundation and habitat responses to climate change. For example, high precipitation may reduce salinity, and this may be harmful for some saltmarsh species (Charles & Dukes 2009, McKee *et al*. 2012). Also excluded from this study were the direct impacts of changes to temperature and precipitation on species and habitats.

Present management and future implication

Most of Victoria's 16 coastal IBAs have an element of protection, as they overlap with different protected areas and Ramsar sites. However, it appears, from their protected area management plans and Ramsar Management Plan Strategy direction, that inundation due to SLR has not been considered as a direct threat to these areas. While some plans include salinity and erosion as key risks to coastal wetlands (Resources & Environment 2002a, Victoria 2003, Vasey-Ellis 2009), only Swan Bay & Port Phillip Bay and Werribee & Avalon have listed storms or floods as a future threat (Victoria 2003) (Birdlife International 2015a-p). Although the Victorian Coastal Strategy (2014), and Coastal Hazard Management Guide (2012) considered inundation models at the state scale, clear plans for the management of SLR impacts on the IBAs and associated protected areas were not found.

Poor management of a coastal area may increase exposure to habitat loss. For instance, in Denmark, ~ 51% of saltmarsh area is poorly managed, threatening bird populations due to the lack of food and proper breeding areas. Further, 15.3-43.6% of current saltmarsh was projected be lost by the end of the century due to poor management and SLR (Clausen *et al*. 2013). Given that for some Victorian IBAs (e.g. Bellarine Wetlands, Swan Bay & Port Phillip Bay Islands, Corner Inlet etc.) the majority of inundation is projected to occur within the next few decades, it is imperative that specific strategies to facilitate adaptation of these areas be developed and implemented in the near future. Equally important is a state-wide assessment of potential inundation of all coastal habitats to identify regions that may become important sites for birds in the future. This study has implications for the conservation of globally threatened wetland bird species such as hooded plover, far eastern curlew, Australasian bittern and fairy tern that occurs in the coastal IBAs of Victoria (Appendix 3 for details). Conservation of the land that can allow the uplift of saltmarsh and intertidal flat areas (Iwamura *et al.* 2014) or habitat reallocation to nearby areas may assist with maintaining bird populations.

In conclusion, this study reveals how sea level rise may inundate Important Bird and Biodiversity areas across Victoria, and that this facet of climate change urgently needs to be given greater attention in management of coastal habitats.

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Supplementary Materials

Appendix 1: **Table A1** The details of Important Bird and Biodiversity Area (IBAs) included in this study (Source: OzCoasts 2008, BirdLife International 2014, BirdLife International 2015a-p, etc)

IBA Name	Location	IBA categories	IBA Triggered species (number)	IUCN Categories	Habitat type (IUCN)	Habitat details	Estuary
Anderson Inlet	145° 47.69' East 38° 39.46' South	A1, A4i	Orange-bellied Parrot (6)	Critically Endangered	Coastline, shrubland, induced vegetation	Intertidal mud, sand & salt flats, mangrove wetlands, saltmarshes	Wave dominated
			Red-necked Stint (543-63,90)	Least Concern			
Bellarine Wetlands	144° 26.68' East 38° 13.22' South	A1, A4i	Chestnut Teal (1,200)	Least Concern	Coastline and wetlands	Estuarine waters, intertidal mud, sand & salt flats, saltmarshes, sand cays, islets & bars, permanent herbaceous swamps & bogs, saline lakes, salt marshes	Wave and tide dominated
			Australasian Bittern(12)	Endangered			
			Banded Stilt (5000)	Least Concern			
			Red-necked Stint (2, 205-12, 310)	Least Concern			
			Sharp-tailed Sandpiper (541-5,591)	Least Concern			
			Orange-bellied Parrot (12)	Critically Endangered			
Cheetham & Altona	144°48.20' East 37° 53.45' South	A4i	Chestnut Teal (883-1764)	Least Concern	Coastline, shrubland, wetland, induced vegetation, artificial terrestrial and aquatic	Intertidal mud, sand & salt flats, saltmarshes, ephemeral, freshwater lakes & pools, saline lakes	Tide dominated
			Red-necked Stint (160-400)	Least Concern			
			Pacific Gull (148-316)	Least Concern			
Corner Inlet	146° 28.84' East 38° 44.35' South	A1, A4i	Chestnut Teal (562-1764)	Least Concern	Coastline, shrubland	Estuarine waters, intertidal mud, sand & salt flats; mangrove wetlands, sand cays, islets & bars	Wave dominated
			Pied Oystercatcher (531-914)	Least Concern			
			Sooty Oystercatcher (160-400)	Least Concern			
			Hooded Plover (22-35)	Vulnerable			
			Far Eastern Curlew (552-1971)	Vulnerable			
			Red-necked Stint (12,663-22,720)	Least Concern			
			Pacific Gull (204-543)	Least Concern			
			Fairy Tern (22-50 breeding pair)	Vulnerable			
			Orange-bellied Parrot (2)	Critically Endangered			
Discovery Bay to Piccaninnie Ponds	141° 13.29' East 38° 10.74' South	A1, A2, A3	Australasian Bittern (2-3 breeding pair)	Endangered	Coastline, shrubland, wetlands	Other shrubland, salt flat, intertidal mud flat, sand, fresh water lakes and pools	Wave dominated
			Hooded Plover (15-51)	Vulnerable			
			Orange-bellied Parrot	Critically Endangered			
			Rufous Bristlebird(frequent)	Least Concern			
			Striated Fieldwren (uncommon)	Least Concern			

IBA Name	Location	IBA categories	IBA Triggered species (number)	IUCN Categories	Habitat type (IUCN)	Habitat details	Estuary type
Gippsland Lakes	147° 32.94' East 38° 0.95' South	A1, A4i	Black Swan (10,000)	Least Concern	Coastline, forest, shrubland, wetlands	Lagoons, sand cays, islets & bars, saltmarsh, intertidal flat, melaleuca forests & woodlands, shrubs, freshwater lakes & pools, saline lakes	Wave dominated
			Chestnut Teal (3,370)	Least Concern			
			Musk Duck (200-750)	Least Concern			
			Fairy Tern (5-80)	Vulnerable			
Lower Brodribb River	148° 33.89' East 37° 45.28' South	A1	Australasian Bittern (1-3)	Endangered	Wetlands	Freshwater lakes & pools, saltmarsh, permanent herbaceous swamps & bogs	Wave dominated
Otway Range	143° 40.91' East 38° 35.87' South	A2, A3	Rufous Bristlebird (frequent)	Least Concern	Forest	Eucalypt open forests, eucalypt tall open forests, eucalypt woodlands rainforest & vine thickets	Wave dominated
			Striated Fieldwren (uncommon)	Least Concern			
			Pink Robin (uncommon)	Least Concern			
Phillip Island	145° 12.76' East 38° 31.18' South	A1, A4i, A4ii	Little Penguin (26,000)	Least Concern	Grassland and shrubland	Tussock grasslands, Chenopod shrubs, samphire shrubs and forblands; other shrubland	Tide dominated
			Short-tailed Shearwater (450, 000)	Least Concern			
			Hooded Plover (21-42)	Vulnerable			
			Pacific Gull (52-490)	Least Concern			
Port Fairy to Warrnambool	142° 22.86' East 38° 21.55' South	A1	Hooded Plover (15 breeding pair)	Vulnerable	Coastline, shrubland, wetlands, induced vegetation	Grassland, pasture, Estuarine waters, intertidal mud, sand & salt flats, permanent herbaceous swamps & bogs, shrubland	Wave dominated
			Orange-bellied Parrot (17)	Critically Endangered			
Shallow Inlet	146°9.20' East 38° 49.22' South	A1, A4i	Double-banded Plover (538-597)	Least Concern	Coastline, shrubland	Estuarine waters, intertidal mud, sand & salt flats, salt marshes, sand cays, islets & bars	Wave dominated
			Red-necked Stint (3,366-5,421)	Least Concern			
			Orange-bellied Parrot (1)	Critically Endangered			
Swan Bay & Port Phillip Bay Islands	144° 40.04' East 38° 14.25' South	A1, A4i	Chestnut Teal (1300-4000)	Least Concern	Coastline, shrubland, wetland, artificial terrestrial	Intertidal mud, sand & salt flats, lagoons, sand cays, islets & bars, sea cliffs, rocky shores & rocky islets, freshwater lakes & pools, saltmarshes	Tide dominated
			Blue-billed Duck (416)	Near Threatened			
			Australian Ibis (12,000)	Least Concern			
			Straw-necked Ibis (15,000)	Least Concern			
			Red-necked Stint (1,385-9,000)	Least Concern			
			Larus (4000-500000 pair)	Not Recognised			
			Fairy Tern (240)	Vulnerable			
			Orange-bellied Parrot (3-9)	Critically Endangered			

IBA Name	Location	IBA categories	IBA Triggered species (number)	IUCN Categories	Habitat type (IUCN)	Habitat details	Estuary
Werribee & Avalon	144° 33.16' East 38° 1.58' South	A1, A4i	Freckled Duck (57-595)	Least Concern	Artificial - aquatic, coastline, wetlands	Intertidal mud, sand & salt flats, saltmarshes, freshwater lakes & pools, other artificial wetlands	Tide dominated
			Australian Shelduck (3,081-18,230)	Least Concern			
			Pink-eared Duck (17,028-50,985)	Least Concern			
			Australian Shoveler (6,608- 17,433)	Least Concern			
			Chestnut Teal (5799-10,064)	Least Concern			
			Blue-billed Duck (1784-13000)	Near Threatened			
			Musk Duck (1436-2103)	Least Concern			
			Hoary-headed Grebe (14,055-24881)	Least Concern			
			Red-necked Stint (5603-15110)	Least Concern			
			Sharp-tailed Sandpiper (586-4060)	Least Concern			
			Orange-bellied Parrot (20)	Critically Endangered			
Western Port	145° 20.87' East 38° 21.32' South	A1, A4i	Pied Oystercatcher (233-391)	Least Concern	Coastline	Estuarine waters, intertidal mud, sand & salt flats, mangrove wetlands, saltmarshes, shingle & stony beaches	Tide dominated
			Far Eastern Curlew (557-872)	Vulnerable			
			Red-necked Stint (4,246-8,903)	Least Concern			
			Pacific Gull (118-540)	Least Concern			
			Fairy Tern (2-108)	Vulnerable			
			Orange-bellied Parrot (5)	Critically Endangered			
Carrum Wetlands	145° 10.00' East 38° 4.00' South	A1, A4i	Chestnut Teal (1,962)	Least Concern	Wetlands (inland), artificial - aquatic	Ephemeral, freshwater lakes & pools, other artificial wetlands	
			Blue-billed Duck (510)	Near Threatened			
			Australasian Bittern (14)	Endangered			
			Sharp-tailed Sandpiper (5,839)	Least Concern			
Yambuk	142° 2.02' East 38° 19.20' South	A1	Australasian Bittern (common)	Endangered	Coastline shrub land	Chenopod shrubs, samphire shrubs and forblands, estuarine waters, intertidal mud, sand & salt flats; saltmarshes	
			Hooded Plover (45-76)	Vulnerable			
			Orange-bellied Parrot (2-18)	Critically Endangered			

Appendix 2: Table A2 Threats to Important Bird and Biodiversity Areas along coastal Victoria, and number of protected area (Source: Resources and Environment. 2002a,b, Victoria 2003, BirdLife International 2015a-p)

IBA NAME	Threats other than SLR	No. of protected areas
Anderson Inlet	Human interference, urbanization, invasive species occurrence , industrialization, agriculture	1
Bellarine Wetlands	Human interference, natural system modification, urbanization, invasive species occurrence, industrialization, agriculture	1
Cheetham & Altona	Residential and commercial development	3
Corner Inlet	Human interference, urbanization, invasive species occurrence, industrialization, agriculture	6
Discovery Bay to Piccaninnie Ponds	Human interference, invasive species occurrence	3
Gippsland Lakes	Human interference, urbanization, invasive species occurrence, industrialization, agriculture, climate change, pollution	11
Lower Brodribb River	Natural system modification, agriculture	3
Otway Range	Natural modification, invasive species	1
Phillip Island	Human interference, natural system modification, urbanization, invasive species occurrence, industrialization, agriculture, biological resource	1
Port Fairy to Warrnambool	Human interference, invasive species occurrence	1
Shallow Inlet	Human interference, urbanization, invasive species occurrence, industrialization, agriculture	1
Swan Bay & Port Phillip Bay Islands	Human interference, urbanization, invasive species occurrence, industrialization, agriculture, flood, storm	6
Werribee & Avalon	Human interference, urbanization, invasive species occurrence, industrialization, agriculture, climate change, pollution	1
Western Port	Human interference, urbanization, invasive species occurrence, industrialization, agriculture, flood, storm	7
Carrum Wetlands	Invasive species, pollution, natural modification	1
Yambuk	Human interference, natural system modification, agriculture	1

Appendix 3: Table A3 Potential habitat area (saltmarsh, intertidal flat, mangrove and other geomorphic features of 16 IBAs projected to be inundated by 2040, 2070 and 2100, due to 0.2 m, 0.47 m, and 0.82 m sea level rise (SLR), respectively

IBA No	IBA Name	Projected future scenarios for habitat inundation											
		Saltmarsh				Intertidal Flats				Mangrove			
		Total_ Area	2040 (km^2 %)	2070 (km^2 %)	2100 (km^2 %)	Total_ Area	2040 (km^2 %)	2070 (km^2 %)	2100 (km^2 %)	Total_ Area	2040 (km^2 %)	2070 (km^2 %)	2100 (km^2 %)
1	Anderson Inlet	1.5	1.1 73.3	1.1 73.3	1.1 73.3	12	4.7 39.2	4.7 39.2	4.7 39.2	0.7	0.5 71.4	0.5 71.4	0.5 71.4
2	Bellarine Wetlands	10.7	9.2 86	10.4 97.4	10.6 99.2	1.1	0.8 72.7	0.9 81.8	1 91	0.2	0.2 100	0.2 100	0.2 100
3	Cheetham & Altona	3.5	1.5 42.8	2.4 70	3.2 91.7	0.8	0.3 34.7	0.4 53.8	0.6 75.3	0	0 0	0 0	0 0
4	Corner Inlet	55.4	41 74	45.2 81.5	47.3 85.4	143.1	26.4 18.4	27.7 19.4	29 20.3	15.1	11.2 74.2	11.7 77.5	12 80
5	Discovery Bay to Piccaninnie Ponds	0.5	0.1 20	0.2 40	0.3 60	0.3	0.1 39.5	0.2 79.1	0.2 79.1	0	0 0	0 0	0 0
6	Gippsland Lakes	56.5	28.4 50.2	38.1 67.4	41.6 73.6	21.3	2.3 10.8	2.4 11.2	2.4 11.2	0	0 0	0 0	0 0
7	Lower Brodribb River	1.8	1.4 77.8	1.5 85.3	1.6 88.8	0	0 0	0 0	0 0	0	0 0	0 0	0 0
8	Otway Range	1	0 0	0.4 40	0.9 90	0.2	0 0	0 0	0.1 50	0	0 0	0 0	0 0
9	Phillip Island	0	0 0	0 0	0 0	0.8	0.2 25	0.3 37.5	0.3 37.5	0	0 0	0 0	0 0
10	Port Fairy to Warrnambool	0.1	0 0	0.1 100	0.1 100	0.1	0.1 100	0.1 100	0.1 100	0	0 0	0 0	0 0
11	Shallow Inlet	10.6	7.3 69.1	7.4 69.4	7.4 69.8	3.4	1.7 52.6	1.8 52.9	1.9 55.8	0	0 0	0 0	0 0
12	Swan Bay & Port Phillip Bay Islands	5.5	4.8 86.8	5.1 92.5	5.3 95.8	0.5	0.5 100	0.5 100	0.5 100	0	0 0	0 0	0 0
13	Werribee & Avalon	2.8	1.2 43	1.5 53.6	1.9 67.8	0.5	0.3 60	0.4 80	0.5 100	0	0 0	0 0	0 0
14	Western Port	25.1	4.7 18.7	7.9 31.5	13.9 55.4	5.5	3.9 71	4.1 74.5	4.4 80	12.6	7.5 59.5	9.4 74.6	11 89

Appendix 4: Figure A1

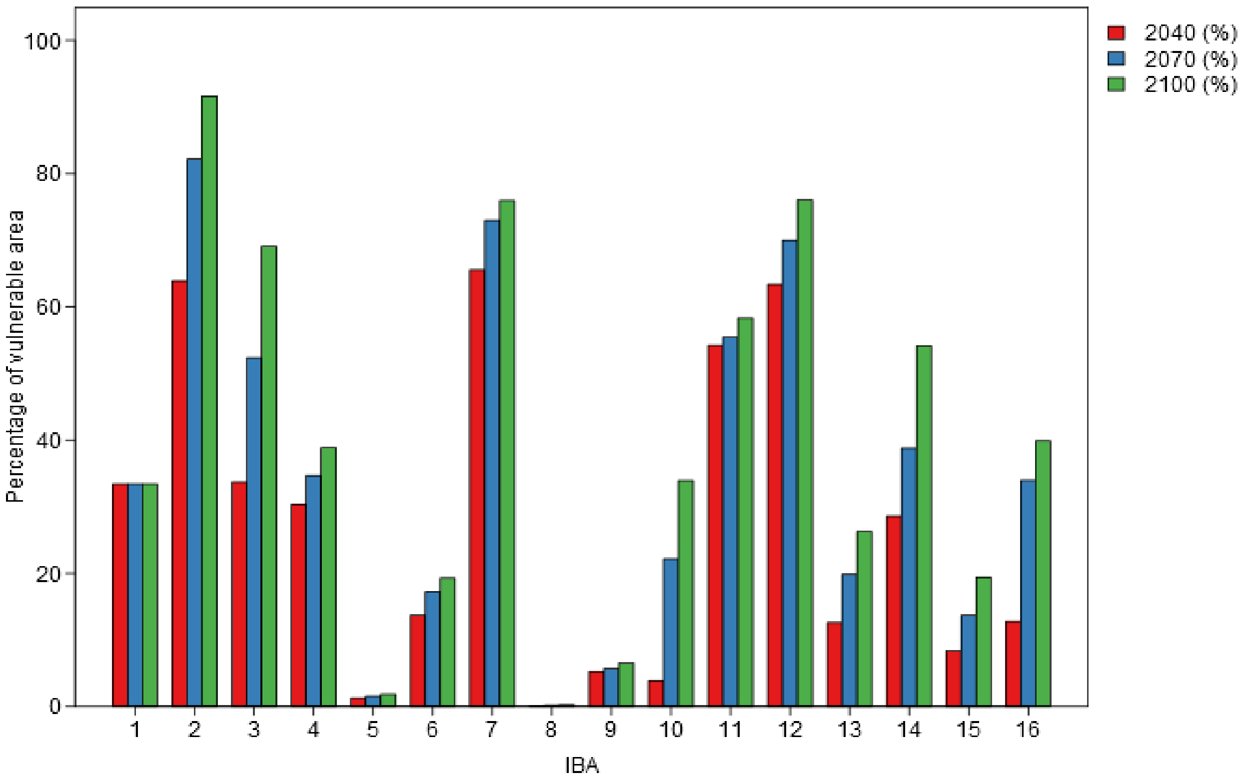

Figure A1: Proportion of Important Bird and Biodiversity Areas (IBA) projected to be inundated due to 0.2m, 0.47 m and 0.82 m SLR by 2040, 2070, and 2100, respectively. Refer to Table 2 for IBA names.

Appendix 5: Figure A2

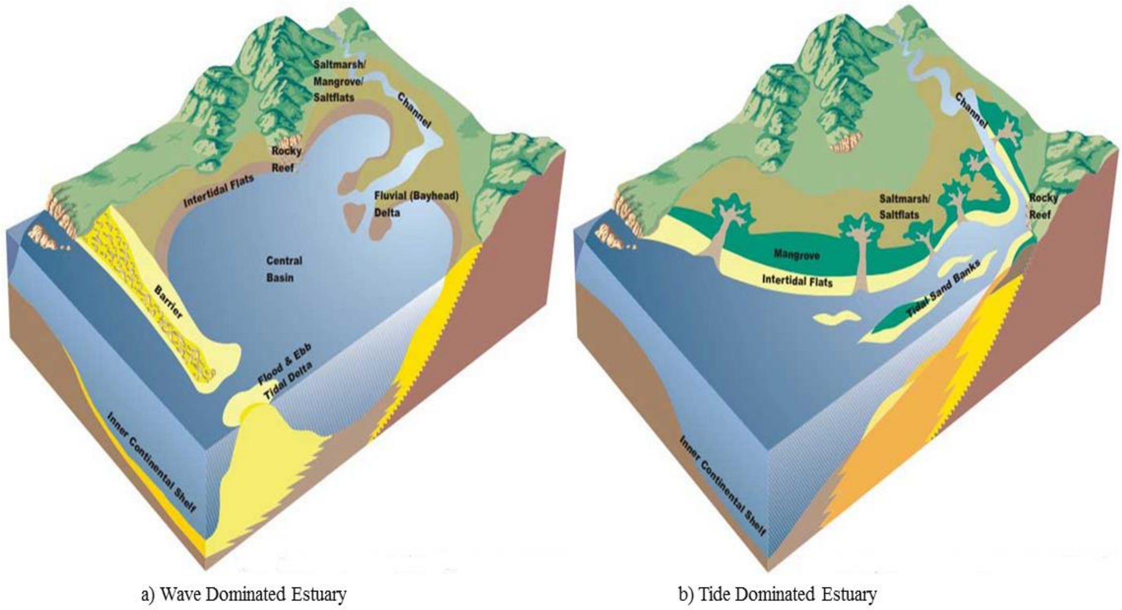

Figure A2: a) Wave Dominated Estuary: the picture is showing the entrance type and position of geomorphic features including back barriers, intertidal flats, saltmarsh and mangrove in a wave dominated estuary; b) Tide Dominated Estuary: the picture is showing the entrance type and position of geomorphic features including position of back barriers, intertidal flat, saltmarsh and mangrove in a tide dominated estuary (Source: Ryan *et al.* 2003).

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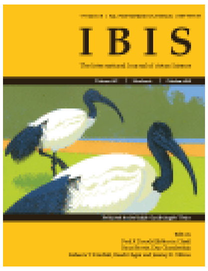

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