

STEPHEN MALLICK
NATURE CONSERVATION REPORT 13/2



Potential Impacts of
CLIMATE CHANGE
on the FAUNA VALUES
of the Tasmanian Wilderness
WORLD HERITAGE AREA

Potential Impacts of Climate Change on the Fauna Values of the Tasmanian Wilderness World Heritage Area

**Stephen Mallick
Nature Conservation Report 13/2**

Department of Primary Industries, Parks, Water and Environment

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Stephen A. Mallick

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SUMMARY

This report provides an assessment of the potential impacts of climate change on the fauna values of the Tasmanian Wilderness World Heritage Area (TWWHA) and identifies management response options.

The report covers fauna values associated with terrestrial, freshwater and estuarine environments, as well as marine mammals which breed and or haul-out on the Tasmanian coast and offshore islands, and beach-nesting shorebirds. The true marine environment and its fauna (pelagic fish, marine invertebrates) are not within the scope of the present report.

The methods used in this report follow the approach of Sharples (2011) and use a standardised risk assessment framework to rank the risk of climate change to the principal fauna habitats of the TWWHA and to priority fauna species. Priority species included the following: species with the majority of their range in the TWWHA, species included in the original nomination of the area for World Heritage listing, and threatened species. The rankings were developed through consultations with a range of Tasmanian researchers, consideration of existing research publications, strategic documents and deliberations from a workshop dealing with research and monitoring priorities for the TWWHA fauna.

There are a number of limitations to be kept in mind in the interpretation of the risk analyses in the present report. First, there are inherent uncertainties in predicting long-term (in the present case 100 year) trends in animal populations, even under 'stable' climate conditions. Second, the risk analyses rely on the best currently available climate projections for the State (from the Climate Futures for Tasmania project: Grose et al. 2010) which are at a relatively fine scale of resolution compared to other parts of the globe (at a scale of 0.1 degrees, or ca. 10 km). Nevertheless, the climate modelling provides only the best-available projections under the current state of knowledge regarding climate change, and future projections of climate change may alter as new knowledge becomes available and the existing models are tested against empirical trends. Finally, risk analyses of the potential impacts of climate change on fauna species are constrained by the availability of information on the ecology and physiology of individual species, which varies greatly from species to species and is often largely lacking for entire groups of animals (such as many invertebrates).

Fauna habitats, World Heritage fauna values, and priority species identified as High risk from the effects of climate change are listed below. Note that only priority species were subject to risk analysis, and the list of high risk species is not intended to be a complete inventory of all fauna likely to be impacted by climate change in the TWWHA. A number of the fauna habitats ranked as most at risk from climate change are found primarily within and or have their most characteristic expression within the TWWHA, notably alpine heathlands and a range of freshwater habitats. Many of these High risk habitats are World Heritage values identified in the original listing of the TWWHA due to their high levels of (Tasmanian) faunal endemism and the high numbers of primitive, relictual or Gondwanan taxa, particularly among the invertebrate fauna. As a result, climate change is predicted to have significant and adverse impacts on many of the specifically World Heritage fauna characteristics of the TWWHA.

Fauna habitats of the TWWHA ranked as High risk from the effects of climate change over the 21st century.

High risk habitats

Estuaries

Central Plateau lakes and other wetlands – shallow and poorly-connected

Central Plateau rivers and streams – low and high groundwater input

Lowland lakes and other wetlands – shallow and poorly-connected

Lowland rivers and streams (upper catchment) – low and high groundwater input

Lowland rivers and streams (lower catchment) – low groundwater input

Alpine coniferous heathland and montane (coniferous) rainforest

Alpine grasslands and non-coniferous heathland

Sphagnum peatland

World Heritage fauna values and exemplar taxa used in the listing of the TWWHA which are ranked as High risk from the effects of climate change over the 21st century.

Listing criteria

Natural criterion (i) outstanding examples representing the major stages of the earth's evolutionary history.

Natural criterion (ii) outstanding examples representing significant ongoing geological processes, biological evolution and man's interaction with his natural environment.

Natural criterion (iii) Superlative natural phenomena, formations or features.

Natural criterion (iv) contains the most important and significant habitats where threatened species of plants and animals of outstanding universal value from the point of view of science and conservation still survive.

Fauna values and exemplar species

Relict biota which show links to ancient Gondwanan biota (exemplar taxa: Orange-bellied Parrot, Tasmanian Tree Frog).

Aquatic insect groups with close affinities to groups found in South America and New Zealand.

Primitive taxa showing links to fauna more ancient than Gondwana (exemplar taxa: Anaspids: Hickman's Pygmy Shrimp, moths in the subfamily Archiearinae: *Dirce aesiodora*, *D. oriplancta*).

Endemic members of invertebrate groups.

Skinks in the genus *Niveoscincus* which demonstrate adaptive radiation in alpine heaths and boulder fields on mountain ranges.

Port Davey-Bathurst Harbour sessile invertebrate communities.

Pedra Branca Skink *Niveoscincus palfreymani*.

Ten priority vertebrate species and three priority invertebrate species were ranked as High risk from the effects of climate change. Four high risk species (3 vertebrate, 1 invertebrate) are associated with habitats in buttongrass moorland including pools, swamps and streams; six species occur in alpine habitats (four vertebrates and two invertebrates); one is a coastal vertebrate (Pedra Branca skink); and two are endemic and threatened galaxias from the Central Plateau (Clarence Galaxias and Western Paragalaxias).

Priority fauna species of the TWWHA ranked as High risk from the effects of climate change over the 21st century *

Vertebrates

Orange-bellied Parrot	<i>Neophema chrysogaster</i>	Buttongrass moorland
Tasmanian Tree Frog	<i>Litoria burrowsae</i>	Buttongrass moorland
Moss Froglet	<i>Bryobatrachus nimbus</i>	Subalpine habitats
Northern Snow Skink	<i>Niveoscincus greeni</i>	Alpine habitats
Southern Snow Skink	<i>Niveoscincus microlepidotus</i>	Alpine habitats
Mountain Skink	<i>Niveoscincus orocryptus</i>	Alpine habitats
Pedra Branca Skink	<i>Niveoscincus palfreymani</i>	Coastal habitats
Clarence Galaxias	<i>Galaxias johnstoni</i>	Highland lakes and streams
Western Paragalaxias	<i>Paragalaxius julianus</i>	Highland lakes
Swamp Galaxias	<i>Galaxias parvus</i>	Buttongrass moorland swamps

Invertebrates

Hickman's Pygmy Shrimp	<i>Allanaspides hickmani</i>	Buttongrass moorland
Pencil Pine Moth	<i>Dirce aesiodora</i>	Alpine coniferous vegetation
Miena Micro-caddisfly	<i>Oxyethira mienica</i>	Highland buttongrass moorland streams

*Only priority species in the TWWHA were subject to risk analyses, and this list is not intended to be an exhaustive list of fauna species at risk from climate change in the TWWHA. Priority fauna species = species with the majority of their range in the TWWHA, species included in the original area for World Heritage listing, and threatened species.

Climate change is also likely to result in changes to the risk posed by invasive fauna species already present in the TWWHA, and to lead to novel invasive species and fauna diseases entering and establishing in the TWWHA. One habitat at very high risk from invasive species is the globally unique Port Davey-Bathurst Harbour estuarine system. While the majority of sessile invertebrate species of the estuary have not been formally described (and are therefore not listed in the table above of High risk priority species), they are likely to include a very high proportion of endemic taxa which are unique to this unusual estuarine system.

Management of these changes to the fauna values of the TWWHA are likely to be severely constrained by the enormous magnitude of shifts envisaged in terms of both spatial scale and the number of fauna species affected. The overarching management approach recommended by the present report is summarised below. Specific management recommendations and actions are detailed in Section 10 of the report.

Overarching management recommendations for addressing the potential impacts of climate change on the fauna values of the TWWHA include:

- As a minimum, maintain the current level of protection of the TWWHA into the future, regardless of changes to the area's natural systems, habitats, flora and fauna, and the World Heritage values on which the area was originally listed.
- Instigate and pursue a change in the paradigm for management of biodiversity within the TWWHA from one centred on 'how to preserve biodiversity in its current form' to 'how to minimise loss'.
- Pursue a shift in management focus from preservation of individual species including threatened species to management approaches at the habitat, landscape and ecosystem level that are effective for many species without necessarily needing to assess the vulnerability and management needs of individual species.
- Continue to use fire management (planned burning) and biosecurity measures as primary conservation management tools within the TWWHA, and modify as required to meet the new demands of climate change.
- Establish ongoing monitoring of selected high risk species and habitats within the TWWHA to verify the reality and extent of fauna and habitat shifts under climate change and to underpin future management and policy directions for the TWWHA.

CONTENTS

SUMMARY	i
1.0 PROJECT SCOPE AND APPROACH	1
1.1 Habitats, priority species and TWWHA values.....	1
1.2 Report structure.....	3
2.0 CLIMATE CHANGE IN THE TWWHA	5
2.1 Primary climate variables.....	5
2.2 Secondary (extreme event) climate variables	7
2.3 Consequent habitat variables	8
3.0 FAUNA HABITATS OF THE TWWHA	10
4.0 CLIMATE CHANGE AND FAUNA HABITATS: A RISK ANALYSIS FRAMEWORK.....	12
5.0 IMPACTS OF CLIMATE CHANGE ON FAUNA HABITATS	14
5.1 Coastal habitats.....	14
5.2 Freshwater habitats	17
5.3 Alpine habitats	25
5.4 Buttongrass moorland	30
5.5 Lowland rainforest	32
5.6 Sclerophyll forest communities	33
5.7 Caves	35
5.8 Estuaries.....	36
5.9 Summary of habitats and risk ranking	38
6.0 PRIORITY SPECIES.....	39
6.1 Species in High risk habitats.....	39
6.2 World Heritage fauna values and exemplar taxa.....	39
6.3 Threatened species	40
7.0 SUMMARY OF HIGH-RISK HABITATS AND SPECIES.....	63
8.0 INVASIVE ANIMALS, DISEASES AND TRANSLOCATIONS	66
8.1 Integrity of the TWWHA	66
8.2 Invasive animals	66
8.3 Diseases.....	68
8.4 Translocations	70
9.0 MANAGEMENT OF IMPACTS OF CLIMATE CHANGE: OVERARCHING APPROACH.....	74
10.0 MANAGEMENT ACTIONS.....	76

10.1	Fire management	76
10.2	Limiting public access to designated areas	77
10.3	Establishment of <i>ex-situ</i> breeding populations	77
10.4	Translocations of species	78
10.5	Monitoring, control and removal of invasive species	78
10.6	Monitoring wildlife diseases	78
10.7	Monitoring of habitat parameters	79
10.8	Modelling future ranges of native species	79
10.9	Targeted Surveys	80
10.10	Monitoring of native species	81
ACKNOWLEDGEMENTS		84
REFERENCES		84
APPENDIX 1		90

1.0 PROJECT SCOPE AND APPROACH

The aims of the present report are to assess the potential impacts of climate change on the fauna values of the Tasmanian Wilderness World Heritage Area (TWWHA) and identify management response options. The report covers fauna values associated with terrestrial, freshwater and estuarine environments, and also considers marine species which have an important life-stage connection with a terrestrial habitat (e.g. marine mammals which breed or haul-out on offshore islands or the Tasmanian coast, and beach-nesting shorebirds). True marine fauna (pelagic fish and marine invertebrates) are not considered here.

The report uses the most recent projections of the Climate Futures project (Grose et al. 2010) on future climate in Tasmania and assumes that these projections are a realistic basis on which to assess potential impacts on the fauna values of the TWWHA. The debate regarding the reality of climate change, the role of anthropogenic CO₂ emissions in climate change, and the reliability of climate change projections is outside the scope of the present report.

1.1 Habitats, priority species and TWWHA values

The TWWHA is located in the western half of Tasmania (Fig. 1) and encompasses around 20% of the Tasmania's landmass. It is a rugged, glacially-formed mountainous region dominated by moorland, rainforest, alpine heathland and grassland and eucalypt forest. In addition to terrestrial and freshwater habitats, the TWWHA encompasses small areas of estuarine habitats such as the south-eastern part of Macquarie Harbour, New River Lagoon and Port Davey-Bathurst Harbour.

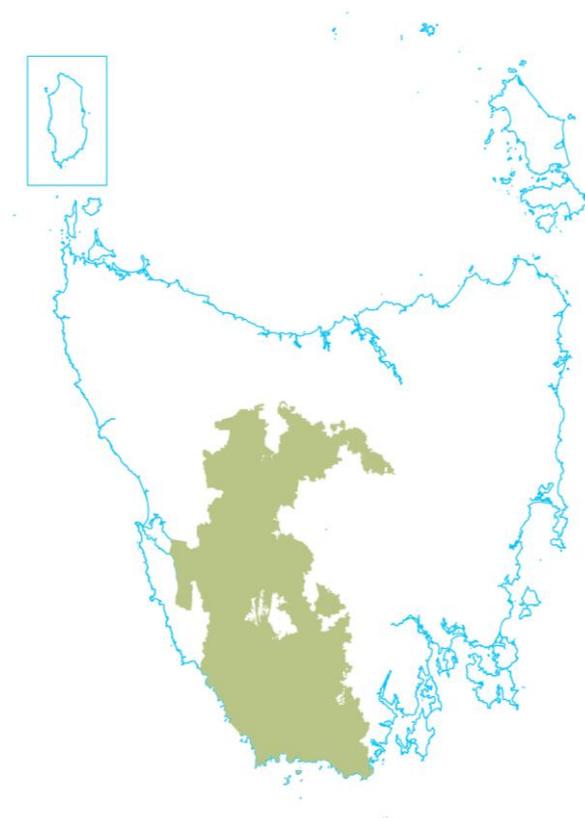


Fig. 1. Location of the Tasmanian Wilderness World Heritage Area.

The term 'fauna values' can be interpreted as inclusive of all fauna species occurring in the TWWHA, or it may denote the subset of fauna species and 'themes' which contributed to the listing of the region as a World Heritage Area under the IUCN World Heritage listing criteria (Anon 1981, 1989). Because of the very large number of fauna species present in the TWWHA and the paucity of information on many (particularly invertebrate) species, it is outside the scope of the present report to assess the potential impacts of climate change on all TWWHA fauna species individually. However, the potential impacts of climate change have been modelled for a small number of TWWHA fauna species, notably the three alpine skinks in the genus *Niveoscincus* (Jungalwalla 2010) and the Broad-toothed Mouse and Swamp Rat (Green et al. 2008), and these species-specific assessments are incorporated in the risk assessments of priority species (Section 6).

Habitat-based approach

In order to narrow the focus to a realistic aim, this report addresses the issue of climate impacts on fauna primarily from a habitat perspective. As part of this habitat approach, the principal fauna habitats of the TWWHA are identified, and a risk assessment is used to rank the potential impacts of climate change on the fauna of each habitat. Fauna habitats include both vegetation communities and habitats not primarily defined by vegetation such as caves, rock scree and freshwater systems. The report by Brown (2009) on the potential impacts of climate change on the vegetation of the TWWHA did not undertake a risk assessment for vegetation communities in the TWWHA. The report 'Vulnerability of Tasmania's natural environment to climate change: an overview' (DPIPWE 2010) included an informal assessment of the risk of climate change to the principal ecosystems of Tasmania. The present report builds on the DPIPWE (2010) report and provides a formally structured risk assessment of the principal vegetation and non-vegetation fauna habitats identified for the TWWHA.

Considering fauna from a habitat perspective provides a practical method of assessing the potential impacts of climate change on large suites of fauna associated with particular habitats. Consideration of habitats is also a useful way to elucidate potential impacts of climate change on the 'overarching' World Heritage values or themes of the TWWHA (e.g. taxa with Gondwanan affinities, relict taxa, etc) for both vertebrates and invertebrates as these themes are frequently strongly allied to specific habitats in the TWWHA. A further advantage of using a habitat approach in considering climate change impacts to fauna is the extensive scale and amplitude of the changes envisioned under climate change. At this unprecedented scale of change (at least in terms of human history), a management response which focuses on individual species is likely to be swamped by the sheer number of species, and indeed ecosystems, undergoing irreversible change over a time span of decades. This issue is discussed in detail in Section 9.

The risk analysis framework follows the approach used by Sharples (2011) in his assessment of the effects of climate change on the geodiversity of the TWWHA. A risk assessment is used to assess and rank the potential impacts of climate change on TWWHA fauna habitats. A risk analysis framework provides a standardised and widely accepted means of increasing the objectivity and transparency of assessments of risk for a wide range of activities and processes including climate change (Rodrigues et al. 2007). However, it is important to note that these risk assessments are a ranking of the potential impacts, and are not necessarily the same as priorities for on-the-ground action to address

these impacts (Sharples 2011). The issue of management actions to address climate change in the TWWHA is discussed in more detail in Sections 9 and 10.

Priority species

In addition to a habitat-based risk assessment approach, this report considers the potential impacts of climate change on a subset of TWWHA fauna referred to as 'priority species'. Priority species include the following (note there is considerable overlap in the following categories):

- 'High risk' vertebrates, defined as species with the majority or the entirety of their TWWHA range within a habitat which is assessed as High risk from climate change. For invertebrates, apart from a small number of exceptionally well-studied groups (notably *Allanaspides* and Parastacidae) there is insufficient information available for the majority of invertebrate groups to identify high-risk taxa based on occurrence in High risk habitats;
- Vertebrate and invertebrate taxa which were used as examples of the World Heritage value of the TWWHA when the area was first listed in 1982 and with an expanded area in 1989 (Anon 1981, 1989);
- Species listed as threatened under the Tasmanian *Threatened Species Protection Act 1995* that have been recorded from the TWWHA.

For each priority species, the risks from climate change are given a rating of Low, Medium or High. Risk ratings were based on published information on species and expert opinion. This rating is based on both the projected risks to species' habitats and on readily available physiological and ecological attributes which might effect a species' survival independent of habitat. Note that this rating of risk is a preliminary assessment and does not include modelling of future range. Recommendations for future work on modelling the risk to species are discussed in Section 10.

1.2 Report structure

The report is structured as follows:

- A brief summary of climate projections for the TWWHA in terms of primary climate variables (temperature, rainfall, etc), secondary (extreme event) climate variables (frost days, cold waves, heat waves, wet days, flooding, storm tides, wind hazard), and consequent habitat variables (runoff, river flows, fire frequency and intensity);
- A list of the principal fauna habitats of the TWWHA;
- A risk analysis framework for ranking the severity of potential impacts of climate change on the fauna of each of these habitats;
- A list of all vertebrate species recorded from the TWWHA and their principal habitats (Appendix 1);
- Identification of priority vertebrate species which occur primarily or entirely in habitats which are identified as High risk from climate change and an assessment of risk from climate change for each priority species;
- A summary of the fauna values and exemplar taxa considered to contribute to the World Heritage value of the area, an assessment of the potential impacts of climate change on each World Heritage value and exemplar species;

- A list of all threatened species occurring in the TWWHA and an assessment of risk of climate change for each threatened species;
- Implications of climate change for invasive fauna species and disease and the integrity of the TWWHA;
- Management approaches to addressing the impacts of climate change on fauna values of the TWWHA;
- Recommendations.

2.0 CLIMATE CHANGE IN THE TWWHA

This report uses the latest projections for climate changes for Tasmania to 2100 as modelled by the Climate Futures for Tasmania project (Grose et al. 2010). This project employed as a starting point two of the most recent emissions scenarios for the coming century – the A2 (high emissions) and B1 (low emissions) scenarios from the Intergovernmental Panel on Climate Change’s Special Report on Emissions Scenarios.

The output from these global climate models is at a resolution of 200-300 km, which is too coarse to be useful for climate projections at the scale of Tasmania. Therefore, these models were submitted to a second climate model using downscaling giving a resolution at a scale of 0.1 degrees (ca. 10 km) (Grose et al. 2010). At this scale of resolution, it is possible to make meaningful climate projections for different regions of Tasmania, and to extrapolate these projections in terms of fauna habitats in the TWWHA. The regions discussed by the Climate Futures for Tasmania project which are relevant to climate change and fauna impacts for the TWWHA are the ‘west coast’ (effectively including all of the TWWHA excluding the Central Plateau) and the ‘Central Plateau’.

Climate change in the TWWHA is considered in terms of the following variables which are potentially relevant to impacts on fauna habitats and species:

- (a) **Primary climate variables** (temperature, rainfall, relative humidity, cloud cover, solar radiation, wind speed, relative humidity);
- (b) **Secondary (extreme event) climate variables** (frost days, cold waves, heat waves, wet days, flooding, storm tides, wind hazard);
- (c) **Consequent habitat variables** (runoff, river flows, fire frequency and intensity, sea level rise);

The predicted changes in primary climate variables for the State and for the two TWWHA regions are discussed below and summarised in Table 1.

2.1 Primary climate variables

Temperature

Under a high emissions scenario Tasmania is predicted to experience a state-wide increase in mean temperature of 2.9°C (range 2.6–3.3°C): under the low emissions scenario, Tasmania would experience an increase in mean temperature of 1.6°C (range 1.3–2.0°C). Daily minimum temperature is projected to increase more than daily maximum temperature. Although this increase in temperature is predicted to occur across Tasmania, the increase is predicted to occur more slowly over the western coastal region (Grose et al. 2010).

Note that the projected temperature changes for both emission scenarios are less than the Australian and global average changes for the same period. The small projected changes in Tasmania are largely due to the Southern Ocean storing the excess heat and dust moderating the future Tasmanian climate.

Rainfall

There is no significant change to projected total annual rainfall for the whole of Tasmania under the two emissions scenarios. However, by region there is predicted to be an increase in annual rainfall in coastal areas, and reduced annual rainfall in the Central Plateau region and in some areas of the north-west. There are significant changes in the predicted seasonal patterns of rainfall across the State. The west coast is predicted to experience a significant increase in winter rainfall and a significant decrease in summer rainfall (after 2050). The Central Plateau region is predicted to experience a steady decrease in rainfall in every season throughout the 21st century.

Relative humidity

Annually, average relative humidity under the high emissions scenario is predicted to increase over much of Tasmania by 0.5% to 1.5%, with the exception of the Central Plateau where a slight decrease is projected. Seasonally, the predicted changes in relative humidity are broadly similar to the changes in rainfall. Relative humidity is predicted to decrease in summer and increase in winter on the west coast, and to decline in all seasons on the Central Plateau, particularly in summer.

Cloud cover

Total cloud cover under the high emissions scenario is predicted to decrease by the end of the century, with a spatially complex pattern of change. The regions of greatest reduction in cloud cover are the regions of greatest rainfall decline, particularly the Central Plateau region. The greatest reduction in cloud cover is predicted to occur over the west coast in summer.

Solar radiation

Average annual radiation over Tasmania is predicted to increase in the west and decrease in the east under the high emissions scenario, although the changes are quite small (less than 5%). There is predicted to be a seasonal component to this change, with a slight decrease in radiation in the west in winter, and marked increase in radiation in the west in summer.

Wind speed

The predicted changes to average wind speed are spatially complex. A change in seasonality of mean wind speed is predicted, with higher wind speeds in July to October and lower wind speeds in November through to May. The predicted changes to wind speeds are greater over the oceans surrounding Tasmania than over the land surface.

Evaporation

There is predicted to be a large and significant increase in evaporation under the high emissions scenario, with an increase in pan evaporation of up to 19%. On an annual basis, the increase in evaporation has a fairly even distribution across Tasmania. The increase in pan evaporation is predicted to be greater in summer than in winter, and has a pattern of greater increase in the north and west and less in the east and south. The predicted state-wide increase in temperature is the dominant driver for this increase in pan evaporation.

Table 1. Summary of predicted changes in primary climate variables to 2100 for regions covering the TWWHA (from Grose et al. 2010). Note that ‘region’ refers to the general regional areas of Tasmania discussed by the Climate Futures for Tasmania report and that these areas do not necessarily correspond to distinct bioregions.

Region	Temp.	Rainfall	Relative humidity	Cloud cover	Evaporation	Radiation	Wind speed
West Coast	Increase	Summer: decrease Winter: increase	Summer: decrease Winter: increase	Decrease (esp. summer)	Large increase	Summer: increase	July-October: higher November-May: lower
Central Plateau	Increase	All seasons: decrease	All seasons: decrease	Decrease	Large increase	Minor change	July-October: higher November-May: lower

2.2 Secondary (extreme event) climate variables

Frost days, cold waves

There is predicted to be a reduction in the number of frost days across Tasmania, particularly in the Central Plateau region (a predicted 8-fold decrease in frosts at Miena and Liawenee). Cold waves (defined as three or more days colder than 5°C) are projected to decrease across Tasmania, particularly in the Central Plateau region. The Miena and Liawenee area is predicted to experience a more than 10-fold reduction in the frequency of cold waves consistent with the projected decreases in the frequency of individual frost days.

Heat waves

Heat waves are defined as three or more consecutive days where the maximum temperature is above 28 °C. The Midlands, north coast, Derwent Valley and the south-west around Macquarie Harbour are all projected to have significant increases in the number of heat waves. An increase in the numbers of warm days and warm spells (a series of consecutive warm days) is predicted for all of Tasmania, particularly in the central north and midlands, the Derwent Valley and on the west coast around Macquarie Harbour. Summer days (defined as days when the maximum temperature is greater than 25 °C) are projected to increase across Tasmania, with larger increases at lower elevations. Tropical nights (nights when the minimum temperature is greater than 20 °C) are predicted to increase, mainly in the northern and eastern coastal areas of Tasmania.

Wet days, flooding

Extreme rain events are predicted to increase significantly in both frequency and intensity, leading to a tendency for increases in both drier and wetter conditions over seasonal and annual periods. Most areas of Tasmania are predicted to experience increases in the annual number of very wet days (defined as the wettest 1% of days) with the exception of the Central Plateau and an area extending from the plateau to the north-west. In particular, the west and north-east coastal regions of Tasmania display a pattern of an increasing number of wet days in winter and early spring and a

decrease in summer. These changes are likely to increase the risk of flooding. More intense heavy downpours are also likely to be combined with longer dry periods.

Tidal storm surges

Sea-level rise is felt most acutely during severe storm events, when strong winds and lower than normal atmospheric pressure drive storm surges and high waves further inland. The impacts of these events will be greatest when they occur at high tide and such events can cause coastal inundation and erosion. A rise in mean sea level of between 5 - 14 cm is projected to occur by 2030 under a high emissions scenario leading to water levels associated with a 1-in-100 year storm-tide event occurring as frequently as once every 50 years by 2030.

Wind hazard

Based on both the low on the high emissions scenarios, only moderate increases in wind hazard are projected for Tasmania by 2100 (Grose et al. 2010).

2.3 Consequent habitat variables

Runoff

Runoff is that part of precipitation which is not absorbed and held by soil and which physically moves across the land's surface. Runoff is affected by changes to both rainfall and evaporation-transpiration. Runoff is also affected by changes to rainfall intensity, because more intense rainfall usually leads to proportionately more runoff.

The state-wide annual runoff is predicted to show significant variation from decade to decade throughout the 21st century. On average, state-wide annual runoff is projected to increase only slightly by almost 560 GL, or about 1% (Grose et al. 2010). However, changes to runoff vary between regions, and these patterns of change are more important than the relatively small State-wide changes. Annual runoff is projected to decrease significantly in Tasmania's Central Highlands, with 30% less runoff in some areas. Little change is projected for annual runoff on the west coast. However west coast runoff is projected to increase in winter but decrease significantly in summer and autumn.

River flows

Tasmanian rivers show a diverse range of hydrological characteristics, from high-flowing mountain streams in the west to low-flowing streams in the east. These differences in river flows reflect Tasmania's existing pattern of rainfall. The analysis of extreme events by Grose et al. (2010) suggested that climate change is unlikely to have a significant impact on flooding in large catchments that have significant upstream storages. However, as short-duration rainfall events are likely to become more frequent and intense, small flood-prone catchments that do not have significant upstream storages are predicted to show an increase in the frequency and intensity of downstream flood events. On the west coast a predicted increase in the number of wet days in winter and early spring and an increase in winter runoff are likely to result in significant changes to stream flow patterns (Bennett et al. 2010).

Fire frequency and intensity

Fire frequency and fire intensity is a central ecological process in many of Tasmania's vegetation communities and fauna habitats. As a result, the effect of climate change on fire is likely to be a primary process translating changes in primary climate variables (temperature, humidity, etc) into on-the-ground change in vegetation composition and structure and in fauna habitat. Changes to bushfire regimes in the TWWHA also have the potential to significantly alter geomorphic processes in the TWWHA through destructive impacts on soil and vegetation cover, causing changes such as altered slope stability, water infiltration and runoff rates, erosion and sediment discharge processes and patterns (Sharples 2011).

Fire risk is determined by four factors: the rate of fuel build up; the rate of fuel drying; occurrence of suitable fire days, and sources of ignition (Williams et al. 2009). The influence of climate on fire is extremely complex. As an example, an increase in temperature and a decline in water availability is relatively straightforward: both are likely to increase the rate of fuel drying and the occurrence of suitable fire days. The effect of an increase in atmospheric CO₂ is less clear. More CO₂ can lead to greater potential for photosynthesis and therefore fuel production. However, lack of moisture can inhibit plant growth. A third scenario is that some plants increase their efficiency of CO₂ uptake with a moderate decline in water availability. The effect of a quantifiable change in climate variables on fire involves complex feedback processes which are difficult to predict even for single species and which are fraught with uncertainty for vegetation communities (Lucas et al. 2007). Nevertheless, a number of general predictions can be made for the TWWHA in terms of fire.

- Summers in western Tasmania are predicted to be hotter and drier, leading to an increase in severe fire weather days. It is on extreme fire weather days that most of the total annual area of western Tasmania gets burnt (DPIPWE 2010).
- There has been an increase in the incidence of lightning fires over the previous decade and lightning is now the major cause of wildfire in the WHA, and this trend for greater incidence of lightning fires is predicted to continue (DPIPWE 2010).
- It is predicted that there will be an earlier start to the fire season reducing the window for pre-season fuel reduction burns.
- More frequent and more intense fires are predicted, suggesting that more resources will be required to maintain current levels of bushfire suppression.

3.0 FAUNA HABITATS OF THE TWWHA

Fauna habitats of the TWWHA include vegetation-based habitats (moorland, rainforest, heathland, etc), non-vegetation terrestrial habitats (e.g. caves, rock screes), and estuarine habitats (Table 2). The vegetation-based habitats used in the present report are broad-scale vegetation types and were selected to correspond to a scale which is meaningful in terms of how fauna appear to utilise vegetation as 'habitat', and to be at a sufficiently broad scale to allow meaningful predictions on the potential effects of climate change on vegetation communities.

Table 2. Principal fauna habitats of the TWWHA

Habitat	Notes
Coastal habitats	
Coastal heathland and scrub	Occur patchily in a narrow band along the TWWHA coastline, TWWHA contains a relatively minor component (1%) of State total (Balmer et al. 2004)
Coastal grasslands	Occur patchily in a narrow band along the TWWHA coastline, TWWHA contains a relatively minor component (2%) of State total (Balmer et al. 2004)
Coastal saltmarsh	Saline wetland forming in sheltered coastal locations; highly productive fauna habitat; TWWHA contains small areas of saltmarsh (Balmer et al. 2004)
Beach and dune systems	Extensive pristine sandy beaches and active dune systems occur throughout the TWWHA coastline
Rocky shorelines	Extensive along the TWWHA coastline
Mudflats	-
Offshore islands	TWWHA contains numerous offshore islands, important breeding habitat for marine mammals and birds and the Pedra Branca Skink
Freshwater habitats	
Lakes and other wetlands	TWWHA contains a diverse and unique array of lotic (lake) habitats grading into shallow wetland habitats, ranging from highland tarns to large lowland lakes; support a unique invertebrate and vertebrate fauna with ancient relict elements, (Fulton and Tyler 1993)
Rivers and streams	TWWHA contains a diverse and unique array of lentic habitats, from highland streams to major lowland river systems; support a unique fauna with ancient relict elements, particularly invertebrate taxa (Ponder et al. 1993)
Alpine habitats	
Alpine grasslands	TWWHA contains significant areas of Alpine grassland,

	located mainly in the Central Plateau area, 65% of State total in TWWHA (Balmer et al. 2004)
Alpine heathland: non-coniferous	Extensive areas, 58% of State total in TWWHA (Balmer et al. 2004)
Alpine heathland and montane (coniferous) rainforest	Extremely fire-sensitive vegetation, TWWHA contains the majority (92%) of State total (Balmer et al. 2004)
Bolster heath	Distinctive alpine vegetation dominated (>50%) by cushion plant species, in poorly drained areas, TWWHA contains majority (94%) of State total (Balmer et al. 2004)
<i>Sphagnum</i> peatland	Unique vegetation possibly with distinctive fauna, dominated by species of <i>Sphagnum</i> moss; TWWHA contains majority (80%) of State total (Balmer et al. 2004), mainly in Central Highlands in areas of impeded drainage
Rock screes	Important alpine shelter habitat for a number of mammals and invertebrates
Buttongrass moorland	This fauna habitat covers the mosaic of buttongrass moorland, heathland and scrub mosaic globally unique vegetation dominated by Buttongrass <i>Gymnoschoenus sphaerocephalus</i> on organic peat soils; extensive tracks in the TWWHA, TWWHA contains majority (63%) of State total; moorland occurs in complex mosaic with heathland and scrub as part of post-fire succession of vegetation
Lowland rainforest	Climax forest in the absence of fire, can occur as fire-determined mosaic with moorland and scrub, extensive areas in TWWHA
Sclerophyll forest communities	
Wet eucalypt forest	Significant areas in the TWWHA, much of it seral stage (mixed forest) in succession to rainforest (Taylor et al. 1993)
Dry forest	Extensive areas of <i>E. nitida</i> dry forest occur in the TWWHA (59% State total), minor areas of other lowland dry forest types in the TWWHA (Balmer et al. 2004)
Subalpine woodland	Extensive areas, occurs at intermediate altitudes in highland areas of the TWWHA
Caves	TWWHA contains a diverse array of karst phenomena including several major cave systems supporting unique often cave-obligate fauna (Kiernan and Eberhard 1993)
Estuaries	TWWHA contain significant estuarine habitats, notable the globally unique Port Davey-Bathurst Harbour system, as well as New River Lagoon and Macquarie Harbour

4.0 CLIMATE CHANGE AND FAUNA HABITATS: A RISK ANALYSIS FRAMEWORK

To rank potential impacts of climate change on habitat, this report uses a risk analysis based on the Australia – New Zealand Risk Management Standards (AS/NZS 4360:2004; Standards Australia 2004). To apply a risk analysis to climate change impacts on fauna habitats and species, it is necessary to identify:

- the likelihood of a specified impact on a fauna habitat occurring within a defined time period (in this case 87 years to 2100);
- the level of consequences for TWWHA fauna values if the impact does occur.

The present report uses a 5-level scale for likelihood of a specified impact occurring: *Almost Certain, Likely, Possible, Unlikely, and Rare*. Note that these likelihood ratings are an attempt to scale the likelihood of a specified impact on fauna habitat given the projected climate change scenario outlined in Section 2. They are *not* a description of the likelihood of the climate change occurring *per se* (Sharples 2011).

To assist in the description and ranking of consequences, the present report follows Sharples (2011) in using the overarching management objective of the TWWHA Management Plan (Parks and Wildlife Service 1999) as the base criterion against which the consequences of an impact can be weighed, namely:

‘To identify, protect, conserve, present and, where appropriate, rehabilitate the World Heritage and other natural and cultural values of the WHA, and to transmit that heritage to future generations in as good or better condition than at present.’

Detailed criteria used to rank consequences are given in Table 3.

Based on the estimates for the likelihood and consequences of a specified impact, the risk ranking for that impact is generated using the following matrix. The matrix used to generate risk rankings is modified from the standard matrix, with the categories for Extreme and High combined into a single category for High risk. Note that this ranking is not an *a priori* argument for on-the-ground action to avoid or mitigate the consequences. Rather, it provides a guide for considering whether any mitigation actions can or should be attempted (Sharples 2011). Possible management options to deal with impacts of climate change on the fauna of the TWWHA are discussed in more detail in Sections 9 and 10.

Table 3. Consequences scale and criteria used in risk analysis of impacts of climate change on TWWHA fauna habitats or species.

Consequence	Criteria
Catastrophic	<p>The total loss or profound alteration or degradation of all or the majority of one or more habitats (including regionally-specific habitats associated with a particular region of the TWWHA such as the Central Plateau), leading to:</p> <p>Change in the distribution or abundance of the majority or all of the habitat's constituent fauna leading to the loss of a significant proportion of species.</p>
Major	<p>The substantial alteration or degradation of a large proportion of one or more habitats leading to:</p> <p>Change in the distribution or abundance of a proportion of the habitat's constituent fauna leading to the loss of some species.</p>
Moderate	<p>The substantial alteration or degradation of a limited proportion of one or more habitats, or the slight alteration or degradation of a large proportion of one or more habitats leading to:</p> <p>Significant change in the distribution and or abundance of a proportion of the habitat's constituent fauna but with minimal loss of species.</p>
Minor	<p>Some minor changes to one or more habitats such that most constituent fauna species have the potential to adjust and survive through existing flexibility and or migration to other (including new) habitats. Minor net change in species distribution and or abundance.</p>
Insignificant	<p>No significant impacts on fauna habitats or species.</p>

Likelihood	Consequences				
	Insignificant	Minor	Moderate	Major	Catastrophic
Almost certain	Medium	Medium	High	High	High
Likely	Low	Medium	High	High	High
Possible	Low	Medium	Medium	High	High
Unlikely	Low	Low	Medium	Medium	Medium
Rare	Low	Low	Low	Low	Medium

5.0 IMPACTS OF CLIMATE CHANGE ON FAUNA HABITATS

This section uses a risk analysis to rank potential impacts of climate change on fauna habitats in terms of the consequences for the habitat's constituent fauna. For each habitat, all primary climate variables and consequent habitat variables are listed which have the potential to influence the condition of that habitat. For each climate variable, the potential impact on the habitat are described, the likelihood of the impact occurring is given a rating, and the consequence for the habitat's fauna is given a rating. This is then used to generate a risk ranking for the habitat. Because a given habitat will usually have more than one climate variable listed, the overall ranking for a habitat is taken as the highest ranking impact.

5.1 Coastal habitats

The coastline of the TWWHA comprises one of the longest temperate-zone, wave-dominated coasts in the world having negligible disturbance from human activities other than global sea-level rise and associated climate change effects (Sharples 2003). These undisturbed and high-energy rocky and sandy coasts include a wide variety of fauna habitats. Principal fauna habitats include geo-physical shoreline habitats (sandy beaches and dune systems, rocky shorelines and tidal mudflats), coastal saltmarsh, coastal lagoons, and coastal grassland and heathland (Sharples 2011, DPIPW 2010).

Shoreline habitats and offshore islands

Overall rank: Medium

The principal impacts of climate change on shoreline habitats (beaches, dunes, rocky shorelines and mudflats) and offshore islands of the TWWHA are likely to be sea level rise and the eventual landward recession of the coastline; increasingly frequent flooding of low-lying coastal flats during storm surges; accelerated shoreline erosion; and possibly the destabilising effect of more frequent fires on dune vegetation.

The principal impact of climate change on the coastal environment will be sea level rise leading ultimately to a landwards shift of coastal processes and landforms including shorelines and dunes (Sharples 2011). The likelihood of this impact is rated as Almost Certain. These changes will clearly result in some level of disruption to existing fauna habitats; however the extent of these impacts will depend on the rate of the shoreline recession and the extent to which comparable shoreline habitats reform inland. Shoreline landform systems have migrated both landwards and seawards during past Pleistocene sea-level changes (Sharples 2011, Garnett et al. 2013). The rate and magnitude of change predicted under climate change are likely to be significantly greater compared to past changes (Sharples 2011), although the rate of change over the next 100 years may still be sufficiently gradual to allow re-formation of fauna habitats inland and for the majority of fauna species to adjust to these changes over time. Contemporary factors which may limit the capacity for species to adapt to a shifting coastline include coastal development and increased nest failure rates because of introduced predators (Garnett et al. 2013).

For solid-ground habitats such as cliffs, most offshore islands and rock stacks, a rise in sea level of around 1 m is unlikely to have major impacts in terms of fauna habitat. For shelving habitats such as beach and dune systems, a rise in sea level of around 1 m is predicted to translate into an inland inundation of up to 100 m which will clearly result in the inundation of existing habitat. However, beach and dune systems are highly mobile, and for the majority of gently shelving coastline of the

TWWHA there appears to be few physical or geographical constraints to a landward shift in beach and dune systems (J. Kirkpatrick pers. comm.).

The effect of sea-level rise on coastal breeding vertebrate fauna is likely to be complex, and will depend heavily on interactions with factors which may constrain the capacity of species to adjust such as coastal geomorphology, coastal vegetation, coastal built structures and adjacent land uses (Garnett et al. 2013). For example, Garnett et al. (2013) assessed potential impacts of climate change on coastal bird species based on the extent to which natural adaptation to geo-morphological processes that have been occurring for millennia are likely to interact with human impacts that are likely to disrupt that adaptation, like coastal development and increased nest failure rates because of introduced predators. Garnett et al. (2013) identified six coastal species considered to be highly exposed to the impacts of climate change, and these species are known to breed within the TWWHA: Pied Oystercatcher (*Haematopus longirostris*), Sooty Oystercatcher (*Haematopus fuliginosus*), Fairy Tern (*Sternula nereis*), Little Tern (*Sternula albifrons*), Hooded Plover (*Thinornis rubricollis*), Red-capped Plover (*Charadrius ruficapilla*). Garnett et al. (2013) also examined the potential impacts of changes in marine productivity on marine and coastal. Of the priority species known to breed within the TWWHA, only the Soft-plumaged Petrel was listed as sensitive to the impacts of climate change within the marine habitat.

While the potential impacts of climate change on the six coastal-breeding species identified by Garnett et al. (2013) may be significant at a national level, the exacerbating impacts of coastal development and introduced predators are likely to be minimal along the coastline of the TWWHA. These species are therefore given a risk ranking of Medium within the context of the TWWHA (Table 5), while recognising that over significant parts of their range the species may be significantly impacted by climate change. It should also be noted that the importance of areas such as the TWWHA is likely to increase for these species which are likely to suffer severe impacts in other parts of their range where human development constrains the capacity for the species to adapt to rising sea levels.

Overall for coastal habitats, while there is likely to be some local change in the configuration of soft-ground and shelving coastal habitats along of the TWWHA coastline, the recession of these habitats in the TWWHA is predicted to be sufficiently gradual to allow time for the majority of coastal breeding vertebrates to adjust such that only temporary and local disruptions to populations occur. The impact of these changes on invertebrate fauna is difficult to predict, however the gradual recession in habitat may be sufficiently incremental to also allow invertebrate species to relocate without significant risk of extinction. Based on a minimal impact of sea level rise on cliffs, rock stack and most offshore island habitats, and on the likelihood that most shelving coastal habitats will be able to reform inland, the consequences of impacts of sea level rise on coastal habitats are rated as Minor, giving a risk ranking for coastal habitats of Medium.

Risk analysis for shoreline habitats (beaches, dunes, rocky shorelines and mudflats) and offshore islands

Climate variable	Impacts on habitat	Likelihood of impact	Consequences for fauna	Risk Rank
Sea level rise	Erosion and landward migration of coastal dunes, landward migration of estuarine (mudflat) deposits, inundation of rocky foreshores	Almost certain	Minor	Medium
Storm surges: more frequent, greater intensity	Exacerbation of consequences of sea level rise	Almost certain	Minor	Medium
Increased fire	May destroy stabilising vegetation on coastal dunes making them more susceptible to wind erosion and development of dune blowouts (Sharples 2011)	Possible	Moderate	Medium

Coastal saltmarsh

Overall rank: Medium

Saltmarshes tend to occur in small patches at the higher end of the intertidal zone, generally within bays and at the mouths of creeks and streams. The TWWHA contains only small areas of saltmarsh (Balmer et al. 2004). The principal risk to saltmarsh habitat are sea level rise and inundation of low lying coastal areas, and ongoing erosion and damage to saltmarsh habitat through storm surges. The likelihood of this impact is rated as Almost Certain. As for shoreline habitats, it is difficult to predict how severe the consequences will be on the fauna utilising saltmarshes over the longer term as this will depend on the rate of the shoreline recession and inundation of existing saltmarshes, and the extent to which comparable habitats can re-form inland. Saltmarshes are highly productive habitats that provide food and shelter for a diverse suite of vertebrates including numerous coastal and estuarine birds, as well as supporting the healthy functioning of estuaries (Harris and Kitchener 2005). Although saltmarsh habitat is important as a productive feeding ground for many bird species, the majority of these species also occur elsewhere in the TWWHA and do not rely exclusively on saltmarsh habitat. One exception to this is the threatened Orange-bellied Parrot which forages almost exclusively on coastal saltmarsh vegetation during its migration up the west coast of Tasmania (Orange-bellied Parrot Recovery Team 2006). The invertebrate fauna of saltmarshes in the TWWHA and elsewhere has not been well surveyed and it is not known what proportion of the fauna is obligatory to saltmarsh habitat (P. McQuillan pers. comm.).

Based on the likelihood that ground and shelving habitats including saltmarsh will be able to reform and that most fauna will be able to adjust to a gradual recession in breeding habitats inland, the consequences of impacts of sea level rise and storm surges on saltmarsh are rated as Minor, giving a risk ranking of Medium.

Risk analysis for saltmarsh

Climate variable	Impacts on habitat	Likelihood of impact	Consequences for fauna	Risk Rank
Sea level rise	Inundation and erosion of coastal wetland habitat	Almost certain	Minor	Medium
Storm surges	Damage to coastal wetland habitat inland from high-tide, exacerbation of consequences of sea level rise	Almost certain	Minor	Medium

Coastal grasslands, heathlands and scrub

Overall rank: Medium

The TWWHA supports a relatively small proportion of the State's coastal heathland and coastal grassland vegetation (1% and <2% of State total, respectively) (Balmer et al. 2004). The principal risk is likely to be an increase in fire frequency due to warmer drier conditions and an increased incidence of lightning strike (DPIPWE 2010). An increased fire frequency is likely to lead to changes in species composition and structure in both grassy and heathy vegetation, however the nature of these changes are difficult to predict. The consequences for coastal grassland and heathland fauna are rated as Minor.

Risk analysis for coastal grassland, heathland and scrub

Climate variable	Impacts on habitat	Likelihood of impact	Consequences for fauna	Risk rank
Increased fire frequency and intensity	Vegetation tolerates frequent fire, increased frequency may alter species composition	Likely	Minor	Medium
Higher temperatures, reduced rainfall, increased evaporation	Complex direct effects, difficult to predict; some changes in species composition and structure	Possible	Minor	Medium

5.2 Freshwater habitats

The TWWHA supports an exceptionally diverse range of freshwater habitats including rivers and streams, lakes and wetlands. The combination of cool climate, dark tannin-stained waters and low nutrient levels makes many of these freshwater habitats globally unique. In the present report, lotic habitats ('standing water' habitats including lake habitats grading into shallower wetland habitats) and lentic (river and stream) habitats are considered separately. A further distinction is made between the Central Plateau and non-Central Plateau freshwater habitats in the TWWHA. This distinction reflects the more extreme climate projections for the Central Plateau region (see Section 2). It should be noted that the non-Central Plateau region of the TWWHA also includes significant

areas of high altitude terrain containing freshwater habitats. These high altitude freshwater habitats are not considered separately in the following risk assessments. However, these highland lakes and streams share many of the physical characteristics of the Central Plateau lakes and streams (e.g. small, clear water headwater streams, poorly connected highland lakes), and are likely to experience similar but less extreme impacts of climate change to those predicted for Central Plateau habitats.

'Lakes and other wetlands' covers lotic or 'standing water' habitats. The principal risks to lakes and wetlands in the TWWHA are increased water temperatures, reduced dissolved oxygen due to higher temperatures, reduced rainfall and runoff, and more frequent drying (DPIPWE 2010). The risk from acid sulphate soils is poorly understood, but is likely to be relatively minor for non-coastal lakes and wetland of the TWWHA (P. Davies pers. comm.). The influence of deep water and high connectedness to the surrounding drainage and or groundwater is to buffer the lake or other wetland from the effects of increased temperature and drying. High connectedness also allows greater potential for fauna under stress to disperse to less affected habitats if they are available (P. Davies pers. comm.).

A high proportion of Tasmania's freshwater lakes and wetlands occur on the Central Plateau and many are in near-pristine condition (DPIPWE 2010). These highland lakes, tarns and wetlands provide a highly diverse array of limnological habitats with few analogues elsewhere in Australia (Fulton and Tyler 1993). The vertebrate and invertebrate fauna of highland lakes and wetlands have a high component of ancient and relictual taxa of world heritage significance (Anon 1989, Fulton and Tyler 1993). There is a high level of endemism at the regional scale (i.e. many species endemic to the Central Plateau region). However, local endemism is likely to be somewhat lower. The central highland areas were covered in ice sheets during the last ice age and the fauna is relatively 'recent' and has not had sufficient time to undergo extensive divergence at the catchment or individual lake and river scale (P. Davies pers. comm.). Climate projections for the Central Plateau indicate this region of Tasmania is likely to experience the most significant effects of climate change over the 21st century, with year-round reductions in precipitation and runoff and increases in evaporation in all seasons (Grose et al. 2010).

'Rivers and streams' covers lentic or 'running water' habitats in the TWWHA. The principal risks to rivers and streams in the TWWHA are increased water temperatures, reduced dissolved oxygen due to higher temperatures, altered rainfall and runoff leading to changed flow regimes, and increased extreme rainfall events leading to more frequent flooding, erosion and sediment reworking (DPIPWE 2010, Sharples 2011). Riverine features which can influence (either exacerbate or buffer) the effects of climate change include the level of connectedness to groundwater sources, location in the river system (upper or lower catchment), level of riparian shading (both topographical and vegetation), and water colour (tannin or clear waters).

As for lotic habitats, the streams and rivers of the Central Plateau provide a highly diverse array of upper-catchment, clear-water lentic habitats with few analogues elsewhere in Australia (Ponder et al. 1993, DPIPWE 2010). The vertebrate and invertebrate fauna of highland streams have a high component of ancient and relictual taxa of world heritage significance (Anon 1989, Ponder et al. 1993). There is a high level of endemism at the regional scale (i.e. many species endemic to the Central Plateau region). However, local endemism is likely to be somewhat lower. The central

highland areas were covered in ice sheets during the last ice age and the fauna is relatively ‘recent’ and has not had sufficient time to undergo extensive divergence at the catchment or individual lake and river scale (P. Davies pers. comm.). Climate projections for the Central Plateau indicate this region of Tasmania is likely to experience the most significant effects of climate change over the 21st century, with year-round reductions in precipitation and runoff and increases in evaporation in all seasons (Grose et al. 2010).

Ten freshwater faunal habitats of the TWWHA have been defined according to the following criteria:

- Separation of the highland (predominantly the Central Plateau) and lowland regions, reflecting the different climate projections for the two regions as well as distinct differences in aspects of fluvial morphology;
- Lake and wetland depth: water depth has a profound influence on the susceptibility of a lake or wetland to the effects of increased temperature, reduced rainfall and runoff and resulting drying;
- Lake and wetland connectivity: the connectedness of a lake or wetland to the surrounding drainage and to groundwater can buffer a system thermally, hydrologically and chemically from the effects of increased temperatures, reduced rainfall and increased CO₂ (P. Davies pers. comm.). High connectivity can also provide greater opportunities for fauna to ‘escape’ into less effected habitat (if available);
- Position in the river system (upper or lower catchment).

***Central Plateau lakes and other wetlands – shallow and poorly-connected* Overall rank: High**

Shallow water and lack of connectivity with surrounding drainage or groundwater makes these habitats extremely susceptible. The likelihood of increased water temperatures, reduced dissolved oxygen and for increased drying out of water bodies are all rated as Almost Certain. The consequences for fauna are rated as High rather than Catastrophic due to the generally low levels of local endemism in Central Plateau lake faunas. While the risk of complete loss of these shallow and poorly connected habitats is very high, many of the species may also occur in deep, well connected lakes which are less vulnerable. Risk ranking for this habitat is High.

Risk analysis for Central Plateau lakes and other wetlands – shallow and poorly-connected

Climate variable	Impacts on habitat	Likelihood of impact	Consequences for fauna	Risk rank
Higher temperatures	Increased water temperature	Almost Certain	Major	High
Higher temperatures	Reduced dissolved oxygen	Almost Certain	Major	High
Reduced rainfall, reduced runoff(all seasons)	Partial or complete drying of lake or other wetland	Almost Certain	Major	High

Central Plateau lakes and other wetlands – deep and well-connected **Overall rank: Medium**

Risks and impacts to this habitat are the same as above. However, deeper water and greater connectivity with surrounding drainage or groundwater are likely to buffer this habitat from impacts to some degree. The likelihood of increased water temperatures, reduced dissolved oxygen and partial drying are rated as possible. The consequences for fauna are rated as Moderate due to the increased thermal, hydrological and chemical buffering from groundwater sources, giving a risk ranking for this habitat of Medium.

Risk analysis for Central Plateau lakes and other wetlands – deep and well-connected

Climate variable	Impacts on habitat	Likelihood of impact	Consequences for fauna	Risk rank
Higher temperatures	Increased water temperature, reduced dissolved oxygen	Possible	Moderate	Medium
Higher temperatures	Reduced dissolved oxygen	Possible	Moderate	Medium
Reduced rainfall, reduced runoff (all seasons)	Partial drying, lowered water levels	Possible	Moderate	Medium

Lowland lakes and other wetlands – shallow and poorly-connected **Overall rank: High**

Risks and impacts to shallow and poorly-connected lowland lakes and other wetlands are the same for comparable habitat in the Central Plateau area. However, the climate projections for the lowland areas of the TWWHA are less high, with drier conditions only in summer. In terms of lake faunas, there is a generally higher level of local endemism in lowland lakes compared to highland areas (P. Davies pers. comm.). Therefore, while climate impacts may be less severe, there is an increased potential for loss of species in these lowland lake habitats. Overall, the likelihood of partial drying of these lakes and other wetlands is rated as Likely and the consequences for fauna are rated a Major. The projections for temperature are similar for lowland and highland parts of the TWWHA. Therefore the likelihood of increased water temperatures and reduced dissolved oxygen is rated as Almost Certain, and the consequences for fauna are rated as Major. Overall risk ranking for this habitat is High.

Risk analysis for lowland lakes and other wetlands – shallow and poorly-connected

Climate variable	Impacts on habitat	Likelihood of impact	Consequences for fauna	Risk rank
Higher temperatures	Increased water temperature, reduced dissolved oxygen	Almost Certain	Major	High
Higher temperatures	Reduced dissolved oxygen	Almost Certain	Major	High
Reduced rainfall, reduced runoff (summer)	Partial drying, lowered water levels	Likely	Major	High

Lowland lakes and other wetlands – deep and well-connected

Overall rank: Medium

Risks to deep and well-connected lowland lakes and wetlands are likely to be similar to comparable habitat in the Central Plateau, with the risks of drying somewhat less with a projected decline in rainfall only in summer. The likelihood of partial drying of deep and well-connected lakes and other wetlands is rated as Possible with Minor consequences for fauna. Overall risk rank is Medium.

Risk analysis for Lowland lakes and other wetlands – deep, well-connected

Climate variable	Impacts on habitat	Likelihood of impact	Consequences for fauna	Risk rank
Higher temperatures	Increased water temperature, reduced dissolved oxygen	Possible	Moderate	Medium
Higher temperatures	Reduced dissolved oxygen	Possible	Moderate	Medium
Reduced rainfall, reduced runoff (summer)	Partial drying, lowered water levels	Possible	Minor	Medium

Central Plateau rivers and streams – low groundwater input

Overall rank: High

Streams and rivers which are primarily rainfall-fed are most susceptible to the projected year-round reduction in rainfall on the Central Plateau. The likelihood of increased water temperatures and reduced dissolved oxygen and for reduced flows is rated as Almost Certain. The consequences for fauna from the projected declines in flow and higher water temperatures are rated as High rather than Catastrophic due to the generally low levels of local endemism in Central Plateau river and stream faunas. While the risk of complete loss of precipitation-fed stream habitats is very high, many of the species may also occur in groundwater-fed streams which are less vulnerable. The risks of erosion of stream channels due to a likely increase in extreme rainfall events and flooding is also significant. Risk ranking for this habitat is High.

Risk analysis for Central Plateau rivers and streams – low groundwater input

Climate variable	Impacts on habitat	Likelihood of impact	Consequences for fauna	Risk rank
Higher temperatures	Increased water temperature	Almost Certain	High	High
Higher temperatures	Reduced dissolved oxygen	Almost Certain	High	High
Reduced rainfall, reduced runoff (all season)	Reduced stream flow	Almost Certain	High	High
Increase in extreme rainfall events	More intense floods, scouring of stream bed, channel and stream bank erosion, flushing of sediment and organic matter	Likely	Moderate	High

Central Plateau rivers and streams – high groundwater input

Overall rank: High

Streams and rivers which have a significant contribution from groundwater sources are likely to be hydrologically buffered to some degree. The likelihood for decreased flow in these rivers is rated as Possible, and this will depend on the proportion of water which derives from more reliable groundwater sources. Due to the buffering effects of groundwater and the generally lower levels of local endemism in highland streams, consequences for fauna are rated a Moderate. Risk ranking for this habitat is High.

Risk analysis for Central Plateau rivers and streams – high groundwater input

Climate variable	Impacts on habitat	Likelihood of impact	Consequences for fauna	Risk rank
Higher temperatures	Increased water temperature	Almost Certain	Moderate	High
Higher temperatures	Reduced dissolved oxygen	Almost Certain	Moderate	High
Reduced rainfall, reduced runoff (all season)	Reduced stream flow	Possible	Moderate	Medium
Increase in extreme rainfall events	More intense floods, scouring of stream bed, channel and stream bank erosion, flushing of sediment and organic matter	Likely	Moderate	High

Lowland rivers and streams (upper catchment) – low groundwater input **Overall rank: High**

The risks to upper catchment rivers and streams which are primarily rainwater-fed are similar to comparable habitat in the Central Plateau region. However, the climate projections for the lowland areas of the TWWHA are less extreme, with drier conditions only in summer. The likelihood of reduced flow in summer is rated as Almost Certain. The projections for temperature are similar for lowland and highland parts of the TWWHA; however the effects are likely to be exacerbated by the presence of tannin in waters of lowland streams which significantly increases the absorption of heat by the darker-coloured waters (P. Davies pers. comm.). The likelihood of increased water temperatures and reduced dissolved oxygen are rated as Almost Certain. In terms of stream faunas, there is a generally higher level of local endemism in lowland streams compared to highland areas (P. Davies pers. comm.). Therefore, while climate impacts may be less severe, there is an increased potential for loss of species which are restricted to individual catchments or streams. Risk ranking for this habitat is High.

Risk analysis for lowland rivers and streams (upper catchment) – low groundwater input

Climate variable	Impacts on habitat	Likelihood of impact	Consequences for fauna	Risk rank
Higher temperatures	Increased water temperature	Almost Certain	Major	High
Higher temperatures	Reduced dissolved oxygen	Almost Certain	Major	High
(summer)	Reduced stream flow in summer	Almost Certain	Moderate	High
Increase in extreme rainfall events	More intense floods, scouring of stream bed, channel and stream bank erosion, flushing of sediment and organic matter	Likely	Moderate	High

Lowland rivers and streams (upper catchment) – high groundwater input **Overall rank: High**

Streams and rivers which have a significant contribution from groundwater sources are likely to be buffered to some degree against the projected year-round reduction in rainfall on the Central Plateau. The likelihood for decreased flow in these rivers is rated as Possible, and this will depend on the proportion of water which derives from more reliable groundwater sources. Risk ranking for this habitat is High.

Risk analysis for lowland rivers and streams (upper catchment) – high groundwater input

Climate variable	Impacts on habitat	Likelihood of impact	Consequences for fauna	Risk rank
Higher temperatures	Increased water temperature	Likely	Moderate	High
Higher temperatures	Reduced dissolved oxygen	Likely	Moderate	High
Reduced rainfall, reduced runoff (all season)	Reduced stream flow in summer	Possible	Moderate	Medium
Increase in extreme rainfall events	More intense floods, scouring of stream bed, channel and stream bank erosion, flushing of sediment and organic matter	Likely	Moderate	High

Lowland rivers and streams (lower catchment) – low groundwater input **Overall rank: High**

The risks to lower catchment rivers and streams which are primarily rainwater-fed are likely to be similar to comparable upper-catchment streams, with all impacts moderated by the larger size and water volume of these lower-catchment rivers. Risk ranking for this habitat is High.

Risk analysis for Lowland rivers and streams (lower catchment) – low groundwater input

Climate variable	Impacts on habitat	Likelihood of impact	Consequences for fauna	Risk rank
Higher temperatures	Increased water temperature	Almost Certain	Moderate	High
Higher temperatures	Reduced dissolved oxygen	Almost Certain	Moderate	High
Reduced rainfall, reduced runoff (summer)	Reduced summer stream flow	Likely	Moderate	High
Increase in extreme rainfall events	More intense floods, scouring of stream bed, channel and stream bank erosion, flushing of sediment and organic matter	Likely	Moderate	High

Lowland (lower catchment) – high groundwater input**Overall rank: Medium**

Streams and rivers which have a significant contribution from groundwater sources are likely to be buffered to some degree. Impacts are also likely to be ameliorated by the larger size and water volume of these lower-catchment rivers. Risk ranking for this habitat is Medium.

Risk analysis for Central Plateau rivers and streams – high groundwater input

Climate variable	Impacts on habitat	Likelihood of impact	Consequences for fauna	Risk rank
Higher temperatures	Increased water temperature	Likely	Minor	Medium
Higher temperatures	Reduced dissolved oxygen	Likely	Minor	Medium
Reduced rainfall, reduced runoff (summer)	Reduced stream flow in summer	Possible	Moderate	Medium
Increase in extreme rainfall events	More intense floods, scouring of stream bed, channel and stream bank erosion, flushing of sediment and organic matter	Possible	Moderate	Medium

5.3 Alpine habitats

Alpine fauna habitats follow Balmer et al. (2004) and include both true alpine areas (i.e. above the climatic treeline) and adjacent treeless subalpine areas where the elimination of trees is due to poor soils, cold air drainage and frost. Nearly two-thirds (61%) of Tasmania’s alpine vegetation occurs within the TWWHA. All three of Tasmania’s distinctive alpine flora regions – eastern, central and western – are well represented in the TWWHA; the central and western alpine areas are primarily within the TWWHA and have been identified as having global significance (Balmer et al. 2004).

Alpine grasslands and alpine non-coniferous heathland**Overall rank: High**

Non-coniferous alpine heathland is well represented in the TWWHA, while relatively small areas of alpine grassland occur, primarily in the Central Plateau region (Balmer et al. 2004). Alpine heathland is floristically diverse, dominated by species of Proteaceae and Epacridaceae, and in most cases the current community is probably a seral stage in vegetation succession following fire (Crowden 1999). Alpine heathland has survived substantial shifts in climate over the Pleistocene and has probably undergone periods of expansion and contraction over this time (G. Jordan pers. comm.).

A common prediction for alpine habitats in the Northern Hemisphere under a warmer, drier climate is a shift in high altitude vegetation upwards, which in areas where there is little room to move may result in the loss of areas of alpine heathland habitat (Parmesan 2006;; Sauer et al. 2011). However, in Tasmania there is little evidence for a shift in the tree line, which appears to be stable, and the

direct effects of increased temperature on non-coniferous alpine grassland and heathland may be limited to changes in composition and structure rather than wholesale loss of habitat (G. Jordan pers. comm.)

The most important driver of change in the Tasmanian alpine environment is likely to be increased fire frequency (M. Hovenden pers. comm.). The impacts of increased fire in alpine grassland and non-coniferous heathland are difficult to predict for these largely fire-tolerant habitats. However, unlike alpine coniferous heathland, the effects of increased fire on non-coniferous alpine heathland are likely to be limited to changes to composition rather than wholesale degradation or loss of habitat (M. Hovenden pers. comm.). Another potential risk to alpine heathland is the spread of *Phytophthora* to higher altitudes under warmer conditions. Currently *Phytophthora* is limited to localities where soils warm sufficiently (presently <700 m asl) and hold sufficient moisture (>600 mm pa) (DPIPWE 2010). Due to the complex interaction between the pathogen, soil temperature and moisture, as well as soil microflora and host species, it is difficult to predict the net result of climate change on spread of *Phytophthora* into alpine areas (DPIPWE 2010). Areas exposed to *Phytophthora* are likely to experience some impacts; however the pathogen tends to remove particular species leading to changes in vegetation structure and composition rather than wholesale loss of alpine heathland habitat (G. Jordan pers. comm.).

Alpine grasslands and heathland support a diverse vertebrate and invertebrate fauna, although the latter is relatively poorly known (P. McQuillan pers. com.). Much of the fauna of this habitat may be able to adjust to shifts in composition and structure through either flexibility of migration or both. However, some species with narrow climatic envelopes may be unable to survive despite relatively minor changes in vegetation (e.g. alpine skinks; Jungawalla 2010). The consequences for fauna are rated as Moderate, giving a risk ranking of High.

Risk analysis for alpine grasslands and non-coniferous heathland

Climate variable	Impacts on habitat	Likelihood of impact	Consequences for fauna	Risk rank
Higher temperatures, reduced rainfall, increased evaporation	Complex direct effects, difficult to predict; changes in species composition and structure, increase in robust shrub species and tree species	Possible	Moderate	Medium
Increased fire frequency and intensity	Changes in species composition and structure; some species and habitats may be advantaged	Likely	Moderate	High
Spread of <i>Phytophthora cinnamomi</i>	Changes in species composition, vegetation structure	Possible	Moderate	Medium

Coniferous heathland and montane coniferous rainforest**Overall rank: High**

Coniferous heathland and montane coniferous rainforest form a structural continuum and from a fauna and climate change perspective are best considered as a single habitat. This habitat has a patchy occurrence and is confined to situations topographically protected from fire (Duncan et al. 1993). The vegetation is extremely sensitive to fire, and its current extent appears to have been reduced by up to 80% from fires in the mid 1900's (Crowden 1999). The key threats to this habitat are increased fire frequency and the direct effects of drier conditions and more frequent dry spells. Coniferous heathland and rainforest are killed by fire and the projected increases in fire frequency and intensity due to warmer drier conditions, as well as an increased incidence of lightning strikes, have the potential to remove much of the remaining area of this habitat (DPIPWE 2010). Coniferous heathland and rainforest may also be close to its climatic limit in many areas of Tasmania, with dry conditions leading to dieback and in some cases loss of vegetation (M. Hovenden pers. comm.). As a result, an increase in the frequency and duration of dry periods, particularly in the Central Plateau area, could potentially destroy significant areas of this habitat even in the absence of fire.

Coniferous heathland and rainforest appears to have a distinctive invertebrate fauna, although sampling has been largely non-systematic (P. McQuillan pers. comm.). The invertebrate community associated with this habitat also has a very high proportion of endemic and primitive taxa. Examples of taxa which appear to be restricted to Tasmania's alpine coniferous vegetation include the Pencil Pine Moth (*Dirce aesiodora*), the moth genus *Acalyphes*, Plutellidae moths and Nemorynchidae weevils, and further sampling is likely to increase the numbers of taxa which are obligate on this coniferous habitat (P. McQuillan pers. comm.) and consequences for fauna are rated as Catastrophic. The consequences of increased fire and drier conditions are rated as Major to Catastrophic, giving a risk ranking of High.

Risk analysis for alpine coniferous heathland and montane coniferous rainforest

Climate variable	Impacts on habitat	Likelihood of impact	Consequences for fauna	Risk rank
Increased fire frequency and intensity	Vegetation destroyed by fire	Likely	Catastrophic	High
Drier conditions	Dieback and potentially death of vegetation	Likely	Major	High
Higher temperatures	Complex direct effects, difficult to predict; changes in species composition and structure	Possible	Moderate	Medium
Spread of <i>Phytophthora cinnamomi</i>	Changes in species composition, vegetation structure	Possible	Moderate	Medium

Bolster heath**Overall rank: Medium**

Bolster heath is distinctive alpine vegetation dominated by greater than 50% cover of cushion plant species. Bolster heaths tend to be associated with areas of poor drainage, and the cushion plants are also resistant to fire (Crowden 1999). The principal risks from climate change are drier conditions leading to altered drainage and potentially contraction of some bolster heath. The invertebrate fauna of bolster heaths are poorly known, but this habitat appears to support a distinctive community of invertebrates associated with the extended flowering and rich seed production of cushion plants (P. McQuillan pers. comm.). At least one species, the cushion plant moth *Nemotyla* sp. is restricted to bolster heaths. The consequences for bolster heath fauna are rated as Minor to Moderate giving a risk ranking of Medium.

Risk analysis for alpine bolster heath

Climate variable	Impacts on habitat	Likelihood of impact	Consequences for fauna	Risk Rank
Higher temperatures, reduced rainfall, increased evaporation	Drier conditions may lead to contraction of bolster heaths	Possible	Moderate	Medium
Increased fire frequency and intensity	Cushion plants fire tolerant, may be some changes to species composition and structure	Possible	Minor	Medium
Spread of <i>Phytophthora cinnamomi</i>	Changes in species composition, vegetation structure	Possible	Moderate	Medium

Sphagnum* peatland*Overall rank: High**

Sphagnum peats are a significant TWWHA soil-vegetation association with the majority of *Sphagnum* peatlands occurring in poorly drained situations in the Central Plateau region (Whinam et al. 2001, Sharples 2011). The principal threats to *Sphagnum* peatlands are the increasingly dry conditions forecast for the Central Plateau area and an increase in fire frequency and intensity (Whinam et al. 2001, DIPWE 2010, Sharples 2011). Fire poses a direct threat to *Sphagnum* peatlands through killing of the moss and indirectly by favouring other species such as buttongrass, pineapple grass (*Astelia alpina*) and various woody shrub species (DIPWE 2010), while increased desiccation of *Sphagnum* peatlands is likely to result in reduced rates of peat accumulation and increased erosion (Sharples 2011).

The invertebrate fauna of *Sphagnum* peatlands was examined by Whinam et al. (1989). *Sphagnum* peatlands are a heterogeneous habitat and different sites were found to support different faunal assemblages. Some taxa appeared to be obligate moss dwellers, and *Sphagnum* mires were found to support primitive, archaic and relictual taxa, most notably species of anaspid crustaceans in the family Stygocaridae (Whinam et al. 1989). Although the actual area of *Sphagnum* peatland in the

TWWHA is relatively small, the apparent uniqueness of this habitat and its faunal associations indicate consequences rating of Major is appropriate, giving a risk ranking of High.

Risk analysis for *Sphagnum* peatland

Climate variable	Impacts on habitat	Likelihood of impact	Consequences for fauna	Risk Rank
Higher temperatures, reduced rainfall, reduced runoff	Drying out leading to degradation and erosion of peat	Almost certain	Major	High
Increased fire frequency and intensity	Increased burning and degradation of peat	Likely	Major	High

Rock screes

Overall rank: Low

Rock screes are a common feature on mountain slopes in the TWWHA, and are known to provide refuge habitat for a limited number of small mammals (e.g. Long-tailed Mouse). The endemic grasshopper *Tasmanalpina clavata* is largely restricted to this habitat (Key 1991). Many of the bare boulder scree slopes that occur widely on TWWHA mountains have probably been mostly stable since the Last Glacial climatic phase (Sharples 2011). However some active screes are present on TWWHA mountains, and these are likely to be driven by high-altitude freeze – thaw processes. Generally warmer temperatures, reduced snowfall and reduced frost days are likely to inhibit rock-splitting due to ice-wedging, and reduce ongoing formation of this form of active alpine scree. As the active periglacial processes maintaining these landforms cease, some may be degraded by wind and water erosion (Sharples 2011). However, the impact of this limited degradation on fauna utilising alpine screes is likely to be minimal.

Risk analysis for alpine screes

Climate variable	Impacts on habitat	Likelihood of impact	Consequences for fauna	Risk Rank
Higher temperatures, reduced frost days, reduced snowfall	Reduced ongoing formation of some forms of active alpine scree	Likely	Insignificant	Low

5.4 Buttongrass moorland

Buttongrass moorland

Overall rank: Medium

Tasmania's buttongrass moorland or blanket bogs are a globally unique vegetation type found primarily in Tasmania, and contribute significantly to the area's World Heritage values (Pemberton et al. 2005). The TWWHA contains over 300 000 ha of buttongrass moorland which is nearly two thirds of the State's total (Balmer et al. 2004). Buttongrass moorland occurs over undulating terrain in regions with greater than 2600 mm annual rainfall with high humidity and low evaporation. Decomposition and oxidation of organic matter is inhibited due to the waterlogged condition of the soil and the cool maritime climate, which gives rise to the unique peatland and its associated vegetation (Balmer et al. 2004). Buttongrass moorlands are highly pyrogenic, and a large proportion of the blanket bogs are believed to be an early seral stage in vegetation succession following fire (Jackson 1968; Brown 1993). Buttongrass moorland may also be a climatically marginal mire system as a consequence of relatively dry and mild summers (Pemberton et al. 2005).

Buttongrass moorland occurs in a complex mosaic with heathland and scrub. This mosaic reflects at least in part the fire history of the area and the ongoing succession of the vegetation from recently burnt buttongrass through heathland and scrub to rainforest (Jackson 1968; Brown 1993). From a fauna and climate change perspective, this mosaic is considered as a single habitat category for the following reasons: many shrubby species occur naturally within buttongrass moorland and the distinction between moorland, heathland and scrub is often one of degree and reflects the point reached on the succession following fire; many vertebrate and invertebrate species span all three 'habitats'; and the effects of climate change operate on the peatland soil which supports the mosaic.

The principal risk to buttongrass moorland mosaic are the projected drier conditions in summer leading to reduced organic soil accumulation and increased potential for drying out of organic soils leading to increased oxidation and degradation of peat (Sharples 2011). Increased frequency and intensity of fires is also likely to exacerbate the rate of peat degradation. There is also the potential for impacts of increased spread of *Phytophthora cinnamomi* on buttongrass moorland composition and structure. Sharples (2011) identified the likelihood of impacts of drier conditions on moorland peat soils and increased burning as Likely with Catastrophic consequences for the peatland system. Sharples (2011) noted that these impacts are likely to be more severe and to occur more rapidly on the steeper, better drained slopes compared to poorly drained flats with deeper organic soils.

The effects of drier conditions and increased burning on the peat and associated buttongrass moorland vegetation are likely to be complex. There is general consensus that drier conditions in summer will result in drying out of the peat on better drained slopes, with the potential for loss of organic soils in these areas and significant changes in vegetation composition and structure (Sharples 2011; J. Kirkpatrick pers. comm.). Increased fire frequency on these drier slopes is likely to significantly exacerbate these effects. Where burning is frequent and penetrates the peat, there may be total loss of the peat layer and exposure of bedrock. As the peat dries out, there is likely to be a gradual establishment of shrubby species which eventually penetrate to the deeper, more fertile mineral soils which in turn speeds up the establishment of heathland over buttongrass. One possible result is the replacement on drier slopes of buttongrass moorland with heathy vegetation so that

true buttongrass moorland occurs only on poorly drained sites with deeper peats (M. Hovenden pers. comm.).

It is less clear whether increased dryness in summer will lead to significant degradation of peatlands on the poorly drained flatter areas of the TWWHA. Increased summer dryness will potentially be offset by the increased waterlogging of peats during winter when rainfall is projected to increase throughout lowland areas of the TWWHA. For these areas, there is predicted to be some increased summer drying of peats on flats with potential impacts on fauna which rely on saturated peat soils and hydrated pools and burrows of freshwater crayfish. However, there is unlikely to be major degradation of the deeper peat soils on flats or major change to the buttongrass vegetation on these soils over the next 100 years (Sharples pers. comm.; J. Kirkpatrick pers. comm.).

The vertebrate fauna of buttongrass moorland has been well surveyed and is reasonably well understood (Brown 1993). Buttongrass moorlands are the primary habitat in Tasmania for four terrestrial vertebrates (Broad-toothed Mouse, Ground Parrot, Striated Field Wren and Southern Emu Wren) and provide the foraging habitat for the Orange-bellied Parrot during its breeding season, although many other species also utilise moorland as occasional habitat (Pemberton et al. 2005; Driessen 2007). Two endemic vertebrates (Tasmanian Tree Frog and Swamp Galaxias) occur in pools in buttongrass moorland as well as in other habitats (Brown 1993).

Although buttongrass moorland has not been broadly surveyed for terrestrial invertebrates, there has been systematic sampling in some areas (Greenslade and Smith 1999; Driessen and Greenslade 2004; Driessen et al. 2013). Overall, buttongrass moorland appears to support a rich and varied invertebrate fauna (P. McQuillan pers. comm.). However, it is not clear what proportion of taxa are unique to buttongrass moorland and a significant proportion of the non-aquatic taxa recorded from buttongrass moorland may also occur in adjacent heathland, scrub and forested habitats (M. Driessen pers. comm.). Buttongrass moorland is the predominant habitat for several ancient or relictual invertebrate taxa including a suite of endemic burrowing crayfish (Parastacidae), the so-called living-fossil syncarid crustaceans Hickman's Pygmy Shrimp (*Allanaspides hickmani*) and Marsh Pygmy Shrimp (*A. helonomus*), and the endemic Tasmanian Spotwing dragonfly (*Synthemopsis gomphomacromioides*). The invertebrate fauna occupying the water of crayfish burrows (pholeteros) is also highly unusual and is likely to include a high proportion of ancient and relictual taxa (Horwitz and Knott 1991). The peat of buttongrass moorland represents a unique habitat for the larvae of a suite of invertebrate taxa including tipulid and tabanoid flies (P. McQuillan pers. comm.), and desiccation and degradation of the peat soil is likely to have a widespread impact on this peat-soil fauna.

The likelihood of impacts of drier conditions and fire on buttongrass moorland on slopes are rated as Likely. There are likely to be significant impacts of drying out of peats and loss of buttongrass moorland on slopes on fauna using this habitat. However, the majority of the buttongrass moorland on flat, poorly drained areas throughout the TWWHA is predicted to remain largely unaffected. The impacts on fauna in this habitat is therefore rated as minor, although there may be some effect on the ecology of some species reliant on hydrated peat from the longer and more severe periods of summer drying. Overall, the consequences of drier conditions and fire on the fauna of buttongrass moorland are rated as Minor, giving a risk ranking of Medium.

Risk analysis for buttongrass moorland

Climate variable	Impacts on habitat	Likelihood of impact	Consequences for fauna	Risk Rank
Higher temperatures, reduced rainfall and increased evaporation (summer)	Possible shift from peat deposition to peat oxidation, widespread degradation of organic soils	Likely	Minor	Medium
Increased fire frequency and intensity	Increased wildfire and burning of desiccated peatland leading to significant widespread loss of organic soils	Likely	Minor	Medium
Spread of <i>Phytophthora cinnamomi</i>	Changes in species composition, vegetation structure	Possible	Moderate	Medium

5.5 Lowland rainforest

Lowland rainforest

Overall rank: Medium

Lowland rainforest includes a diversity of floristically distinct communities (Harris and Kitchener 2005) but is here considered as a single faunal habitat. The net effect of the projected warmer drier climate is difficult to predict for the floristically and topographically diverse communities covered by lowland rainforest. Rainforest vegetation in Tasmania has survived substantial shifts in climate over the Pleistocene and has probably undergone periods of expansion and contraction over this time (G. Jordan pers. comm.). The most important impact is likely to be increased fire frequency. Rainforest is a fire-sensitive vegetation and most species are killed by fire (Duncan et al. 1993). The cumulative effect of increased fire may be an overall contraction in rainforest in the TWWHA and replacement with earlier seral-stage sclerophyll vegetation under a warmer drier climate and greater fire frequencies (M. Hovenden pers. comm.).

The vertebrate fauna of rainforest is relatively well known. A wide range of vertebrates utilise rainforest, however there are no vertebrate species which are restricted to rainforest (Brown 1993). The invertebrate fauna of lowland rainforest is relatively poorly understood and only a small proportion of taxa has been collected and formally described (McQuillan 1993). Intensive sampling of the invertebrate fauna of a range of rainforest habitats was carried out by Coy et al. (1993). A series of wildlife directed research grants supporting projects have also targeted a number of different invertebrate taxa within the TWWHA including rainforest habitats (listed in Coy et al. 1993). Although still poorly understood, the invertebrate fauna of Tasmania's lowland rainforest is likely to contain a very high proportion of species endemic to Tasmania and ancient and relictual taxa reflecting the ancient origins of this vegetation type (Coy et al. 1993).

The consequences of climate change for rainforest fauna are likely to be some shifts in species distribution and abundance but are unlikely to result in widespread loss of species. Consequences are rated as Minor to Moderate, giving a risk ranking of Medium.

Risk analysis for lowland rainforest

Climate variable	Impacts on habitat	Likelihood of impact	Consequences for fauna	Risk Rank
Higher temperatures, reduced rainfall, increased evaporation	Complex direct effects, difficult to predict; some changes in species composition and structure	Possible	Minor	Medium
Increased fire frequency and intensity	Most rainforest species destroyed by fire, some shift to early fire-succession vegetation	Possible	Moderate	Medium

5.6 Sclerophyll forest communities

Sclerophyll forest vegetation within the TWWHA occupies a niche at the coolest and wettest extreme of the climatic range for this vegetation type (Taylor et al. 1990). Most of the sclerophyllous communities within the TWWHA represent a seral stage in the succession of the vegetation from moorland to rainforest, a process which is primarily determined by fire frequency (Balmer et al. 2004).

Wet sclerophyll

Overall rank: Medium

Wet forests are dominated by a sclerophyllous (usually eucalypt) tree canopy over an understorey of mesophyllous shrubs, trees or rainforest species, the latter referred to as 'mixed forest' (Balmer et al. 2004). Wet forests require catastrophic fire events for stand replacement. Forest ecosystems are slow-growing and do not have the ability to migrate quickly to more favourable climatic zones, and many eucalypt species also have relatively narrow climatic and geographic envelopes (DPIPWE 2010). Increasing temperature and reduced rainfall combined with increased atmospheric CO₂ are likely to result in significant changes to forest species composition, although the nature of these changes is likely to be complex and difficult to predict (DPIPWE 2010). Increased fire frequency is likely to be the most important influence of climate change on wet sclerophyll habitats in the TWWHA, leading to changes in forest composition and structure, and altering the successional balance between moorlands, scrub, forests and rainforest (DPIPWE 2010). Fire is an integral part of the process leading to the development of tree hollows in sclerophyll forests, where partial burning of the tree crown results in limb death and eventual development of hollows. The effect of increased fire frequency on tree hollow development is likely to be complex and difficult to predict. However, severe and frequent wildfire could potentially lead to killing of trees rather than partial crown death, as well as to the complete loss of moribund (and highly combustible) trees already bearing hollows (DPIPWE 2010).

Sclerophyll habitats including wet forests are relatively productive habitats and contain higher vertebrate fauna diversity than other vegetation types present in the TWWHA, including a diverse avian fauna and a large proportion of the State's mammalian species including all three of the larger

marsupial carnivores (Taylor et al. 1993; Appendix 1). As for other habitats, knowledge of the invertebrate fauna of wet forests is fragmentary. However, present knowledge indicates that the invertebrate fauna of sclerophyll habitats is very diverse, with a high degree of Tasmanian endemism and a diversity of primitive and relict taxa of Gondwanan origins (McQuillan 1993, Taylor et al. 1993). Because of the complexity of interactions of climate, vegetation, fire and fauna it is difficult to predict impacts of climate change on wet forest fauna in the TWWHA, although projected changes in vegetation composition and structure are likely to result in changes in fauna species distribution and abundance. Impacts on fauna are rated as Minor to Moderate, giving a risk ranking of Medium.

Risk analysis for wet sclerophyll

Climate variable	Impacts on habitat	Likelihood of impact	Consequences for fauna	Risk Ranking
Higher temperatures, reduced rainfall, increased evaporation	Complex direct effects, difficult to predict; some changes in species composition and structure	Possible	Minor	Medium
Increased fire frequency and intensity	Vegetation can tolerate fire, increased frequency may alter species composition, possible reduction in hollows through repeated wildfire	Possible	Moderate	Medium

Dry sclerophyll and subalpine woodland

Overall rank: Medium

With the exception of *E. nitida* forests, dry forest habitat is relatively poorly represented in the TWWHA compared to the eastern half of the State. In contrast, subalpine woodlands are extremely well represented in the TWWHA (Balmer et al. 2004). As for wet forests, increasing temperature and reduced rainfall combined with increased atmospheric CO₂ are likely to result in significant changes to dry forest and subalpine woodland composition and structure, although the nature of these changes is likely to be complex and difficult to predict. Increased fire frequency is likely to be the most important influence of climate change on dry sclerophyll and subalpine woodland habitats in the TWWHA, leading to changes in forest composition and structure (DPIPWE 2010).

Knowledge of the invertebrate fauna of the dry forests and subalpine woodland of the TWWHA is very fragmentary. In general, the invertebrate fauna of dry forests represents later speciation events in comparison to wet forests and rainforest, and the proportion of primitive taxa is lower (Taylor et al. 1993). Because of the complexity of interactions of climate, vegetation, fire and fauna it is difficult to generalise about the potential impacts of climate change on dry forest fauna in the TWWHA, although projected changes in vegetation composition and structure are likely to result in some changes in fauna species distribution and abundance. Impacts on dry forest and subalpine woodland fauna are rated as Minor to Moderate, giving a risk ranking of Medium.

Risk analysis for dry sclerophyll and subalpine woodland

Climate variable	Impacts on habitat	Likelihood of impact	Consequences for fauna	Risk Ranking
Higher temperatures, reduced rainfall, increased evaporation	Complex direct effects, difficult to predict; some changes in species composition and structure	Possible	Minor	Medium
Increased fire frequency and intensity	Vegetation can tolerate fire, increased frequency may alter species composition, possible reduction in hollows through repeated wildfire	Possible	Moderate	Medium

5.7 Caves

Caves

Overall rank: Medium

Around 8% of the TWWHA is underlain by carbonate rocks, and the area contains a diverse range of karst phenomena which contributed significantly to the area's world heritage listing (Kiernan and Eberhard 1993). The cave fauna of the TWWHA is rich, varied and of great taxonomic and paleobiogeographical interest. It includes a significant proportion of obligate cave dwellers known only from the TWWHA, many of which are primitive or relict taxa with Gondwanan affinities (Kiernan and Eberhard 1993).

Key factors influencing occurrence and distribution of animals in terrestrial caves are food availability and climate (Barr 1968; Culver 1982; Driessen 2010). Sharples (2011) identified the principal impacts of climate change on cave systems in the TWWHA as increased flash-flooding of caves with increased sediment deposition or reworking, and some net drying and increased seasonal variability in cave moisture levels. Reduced stream flow is likely to impact on food availability and presumably cave humidity, and reduced humidity may reduce suitability of caves for a range of species. This likelihood of impact of reduced stream flow on food availability is rated as Possible. The effect of climate change on cave humidity is likely to be complex and difficult to predict. Under current conditions, drying in caves is generally associated with cold external conditions in winter when warmer air in the cave rises, drawing in outside air which warms up causing evaporation (R. Eberhard pers. comm.). A rise in temperature due to climate change could therefore cause increased cave humidity. Increased temperatures in winter may therefore tend to increase cave humidity. However this impact may be offset by effects such as reduced stream flow and drying of caves, increased windiness or increased exposure due to vegetation shift and potential declines in cave humidity. The likelihood of impacts of higher temperatures on cave humidity is rated as Possible. The impacts of climate change on cave systems will also depend heavily on how buffered individual cave system are from changes to outside temperatures and reduced rainfall and stream flows. The impacts of these impacts on fauna are rated as Minor to Moderate, giving a risk ranking of Medium.

Risk analysis for cave habitats

Climate variable	Impacts on habitat	Likelihood of impact	Consequences for fauna	Risk Rank
Reduced rainfall, reduced runoff	Reduced stream flow effecting prey availability	Possible	Moderate	Medium
Higher temperatures	Complex effects, likely to be increased seasonal variability of moisture levels	Possible	Moderate	Medium
Increased extreme rainfall events	More frequent flooding of caves, increased sediment deposition or reworking (Sharples 2011)	Likely	Minor	Medium

5.8 Estuaries

Estuaries

Overall rank: High

The TWWHA contains three significant areas of estuarine habitat: Port Davey-Bathurst Harbour, New River Lagoon, and the south-eastern section of Macquarie Harbour (Driessen and Mallick 2003). Other habitats under this heading include coastal lagoons with a significant input of seawater leading to an estuarine environment. Of the principal estuarine areas of the TWWHA, the Port Davey-Bathurst Harbour system is of paramount interest as a globally unique estuarine system where an anomalous combination of geo-morphological, climatic, hydrodynamic and hydrological conditions has generated an aquatic environment with a highly unusual mix of flora and fauna (Edgar et al. 1999, 2009). While the majority of sessile invertebrate species of the estuary have not been formally described, they are likely to include a very high proportion of endemic taxa which are unique to the Port Davey-Bathurst Harbour estuarine system (Edgar et al. 2007, 2009). At least one species of fish, the Cusk-eel *Microbrotula* sp., is known only from Bathurst Harbour, while a second fish species, the Maugean Skate *Zearaja maugeanais* known only from the estuarine waters of Bathurst Harbour and Macquarie Harbour (Edgar et al. 2007). The Port Davey-Bathurst Harbour estuary has now been included as a significant contributor to the area's World Heritage value in the recent review of the Outstanding Universal Value for the TWWHA compiled by the Australian and Tasmanian governments and submitted for assessment by the World Heritage Committee.

Estuaries have been identified as at high risk from climate change through impacts on both the marine and freshwater elements of the estuarine system (Edgar et al. 2005). Increased water temperatures may lead directly to many estuarine species falling outside their 'climatic envelopes', as well as to the establishment of 'invasive' warm-temperate species which migrate south under a warmer climate (Edgar et al. 2007). However the most significant impact of climate change is likely to be a change in the depth and transparency of the upper freshwater layer due to reduced summer rainfall, particularly in the Port Davey-Bathurst Harbour system (Edgar et al. 2007, Barrett et al. 2010). Reduced summer rainfall and reduced depth and transparency of the freshwater halocline are likely to result in the broad-scale replacement of the unique sessile invertebrate communities with algae-dominated communities (Barrett et al. 2010). A similar impact is likely in Macquarie Harbour,

however fauna impacts are likely to be less significant as the fauna of this estuary, while containing unique elements and species, is less unusual than the Port Davey-Bathurst Harbour system (N. Barrett pers. comm.).

The likelihood of impacts from rising sea levels, increased temperature of estuarine waters, and the reduction in surface runoff are all rated as either Likely or Almost Certain. Impacts on the fauna of estuarine systems in general, and on the Port Davey-Bathurst Harbour system in particular, are rated as Major to Catastrophic, giving a risk ranking of High.

Risk analysis for estuaries

Climate variable	Impacts on habitat	Likelihood of impact	Consequences	Risk Rank
Sea level rise	Increased saltwater intrusion into estuarine waters, disruption of salt and freshwater stratification, increased salinity	Almost certain	Moderate	High
Storm surges	Exacerbation of consequences of sea level rise	Almost certain	Moderate	High
Increased CO ₂	Increased seawater acidity	Almost certain	Moderate	High
Higher temperatures	Increased water temperature, reduced dissolved oxygen	Almost certain	Moderate	High
Reduced rainfall, reduced runoff (summer)	Reduced depth and transparency of freshwater halocline	Likely	Catastrophic	High

5.9 Summary of habitats and risk ranking

Habitat	Risk
Coastal habitats	
Shoreline habitats and offshore islands	Medium
Coastal saltmarsh	Medium
Coastal grasslands, heathlands and scrub	Medium
Freshwater habitats	
Central Plateau lakes and other wetlands – shallow and poorly-connected	High
Central Plateau lakes and other wetlands – deep and well-connected	Medium
Lowland lakes and other wetlands – shallow and poorly-connected	High
Lowland lakes and other wetlands – deep and well-connected	Medium
Central Plateau rivers and streams – low groundwater input	High
Central Plateau rivers and streams – high groundwater input	High
Lowland rivers and streams (upper catchment) – low groundwater input	High
Lowland rivers and streams (upper catchment) – high groundwater input	High
Lowland rivers and streams (lower catchment) – low groundwater input	High
Lowland rivers and streams (lower catchment) – high groundwater input	Medium
Alpine habitats	
Alpine grasslands and non-coniferous heathland	High
Alpine coniferous heathland and montane (coniferous) rainforest	High
Bolster heath	Medium
Sphagnum peatland	High
Rock screes	Low
Buttongrass moorland	
Buttongrass moorland	Medium
Lowland rainforest	
	Medium
Sclerophyll forest communities	
Wet sclerophyll	Medium
Dry sclerophyll and subalpine woodland	Medium
Caves	
	Medium
Estuaries	
	High

6.0 PRIORITY SPECIES

6.1 Species in High risk habitats

A full list of native vertebrate fauna recorded from the TWWHA (from Driessen and Mallick 2003) and the principal TWWHA habitats in which the species are known to occur are given in Appendix 1. Priority vertebrate taxa are identified as species which occur primarily or entirely in habitats identified as High risk from climate change, or which have an important life stage (e.g. breeding) in a habitat assessed as High risk. Although these priority species occur primarily or entirely in High risk habitats, not all species are equally likely to be impacted due to differences in physiological flexibility and capacity to disperse. Species are therefore ranked as:

- **Low:** species likely to adjust to impacts of climate change on habitat, may be changes in distribution or abundance but low likelihood of extinction;
- **Moderate:** species able to adjust to impacts of climate change on habitat, significant changes in distribution or abundance and possibility of extinction from effects of climate change.
- **High:** species unlikely to be able to adjust to impacts of climate change on habitat, high likelihood of extinction from effects of climate change.

This rating is based on both the projected risks to species' habitats and on readily available physiological and ecological attributes which might effect a species' survival independent of habitat. Note that this rating of risk from climate change is a preliminary assessment and does not include modelling of future range. Recommendations for future work on modelling the risk to species are discussed in Section 10.

Table 4 presents risk ranking for non-marine species. Risk ranking for marine and coastal birds and marine mammals is based on several features including locations of nesting and breeding sites in the TWWHA, level of philopatry (fidelity to nest and breeding site between years), and nesting and breeding habitats (Table 5).

6.2 World Heritage fauna values and exemplar taxa

The TWWHA was inscribed on the World Heritage List for natural World Heritage values in 1982 and with extensions to the original area in 1989 (Anon 1981, 1989) and 2013 (DSEWPC 2013). The World Heritage criteria against which the TWWHA was listed remain the formal criteria for the natural World Heritage values of the area. Note that the natural values used in the nomination of the TWWHA were intended to be illustrative of the World Heritage values of the area, and they do not necessarily constitute a comprehensive list of these values.

The World Heritage fauna values of the TWWHA used in the area's nomination tended to be 'overarching values' within the world heritage criteria with specific vertebrate and invertebrate taxa cited as examples. This report assesses the potential impacts of climate change on these values and on each exemplar species as Low, Medium or High, as above (Tables 6–9).

At the time of writing this report the Australian and Tasmanian governments had revised the Statement of Outstanding Universal Value for the TWWHA and submitted it for assessment by the World Heritage Committee. This revision will not substantially change the TWWHA fauna values recognised in the 1989 nomination other than recognising the world heritage value of the estuarine ecosystem at Port Davey-Bathurst Harbour. The revised statement cites fewer specific vertebrate and invertebrate taxa as examples of the overarching values.

6.3 Threatened species

The TWWHA contains a total of 26 threatened vertebrate species (four mammals, 14 birds, two reptiles and six fish) and 20 threatened invertebrate species (Table 10). While all these threatened species are by definition under some degree of risk, climate change will in many cases exacerbate the existing risk of extinction. The risk from climate change for threatened species is rated as Low, Medium and High, as above (Table 10).

Table 4. Priority species of non-marine vertebrates which have the majority or entirety of their range within High risk habitats and assessment of risk from climate change.

Priority taxa	Principal habitat	Risk factors	Risk Ranking
Mammals			
Broad-toothed Mouse <i>Mastacomys fuscus</i>	Buttongrass moorland	Stronghold in buttongrass moorland within TWWHA, also occurs in subalpine heathland (Driessen and Mallick 2003; Driessen 2002). Climate modelling indicates species will have range restricted to higher altitudes (Green et al. 2008). Likely some reduction in range with loss of moorland habitat over slopes; low likelihood of extinction in TWWHA and elsewhere.	Medium
Swamp Antechinus <i>Antechinus minimus</i>	Buttongrass moorland	Stronghold for species is buttongrass moorland from coast to subalpine areas (Brown 1993), also occurs in dry forest and coastal heathland. Likely some reduction in range with loss of moorland habitat over slopes, low likelihood of extinction in TWWHA and elsewhere.	Medium
Birds			
Orange-bellied Parrot <i>Neophema chrysogaster</i>	Buttongrass moorland	Endangered species with less than 50 birds remaining in the wild, breeds in restricted area of buttongrass moorland in TWWHA (Orange-bellied Parrot Recovery Team 2006). Species at extreme risk of extinction under current conditions. Temporary change in coastal saltmarsh habitats (migratory feeding sites) may exacerbate existing threats (Garnett et al. 2013). The impacts of fire on nesting hollows is difficult to predict, however increased severe wildfire could potentially remove nesting habitat.	High
Ground Parrot <i>Pezoporus wallicus</i>	Buttongrass moorland	Stronghold in buttongrass moorland within TWWHA (Driessen and Mallick 2003). Some loss of buttongrass moorland on slopes may result in a significant reduction in range and or abundance, low likelihood of extinction in TWWHA.	Medium
Southern Emu-Wren <i>Stipiturus malachurus</i>	Buttongrass moorland	Stronghold in buttongrass moorland within TWWHA (Driessen and Mallick 2003). Some loss of buttongrass moorland on slopes may result in a significant reduction in range and or abundance, low likelihood of extinction in TWWHA.	Medium

Priority taxa	Principal habitat	Risk factors	Risk Ranking
Frogs			
Moss Froglet <i>Bryobatrachus nimbus</i>	Cloud forest in subalpine heathland and lowland rainforest	Occurs primarily in subalpine heathland and lowland rainforest within the TWWHA (Rounsevell et al. 1994; Mitchell and Swain 1996). Susceptibility to chytrid not known (Philips et al. 2010). Although not strictly alpine, very restricted range and association with damp subalpine environment indicates potential reduction in range, possibility of extinction under drier conditions.	High
Tasmanian Tree Frog <i>Litoria burrowsae</i>	Buttongrass moorland	Occurs primarily in buttongrass moorland within the TWWHA (Littlejohn 2003). Widespread drying and degradation of buttongrass moorland on slopes likely to result in significant reduction in range and abundance, species is also rated a very high risk from chytrid disease (Philips et al. 2010). Potential exacerbating threat from chytrid and reliance of this species on permanent water warrants a rating of High.	High
Reptiles			
Northern Snow Skink <i>Niveoscincus greeni</i>	Alpine and subalpine	Occurs in open boulder fields in alpine and subalpine habitats, climate modelling predicts extinction by 2085 (Jungalwalla 2010)	High
Southern Snow Skink <i>Niveoscincus microlepidotus</i>	Alpine and subalpine	Occurs in boulder fields, alpine heathland and subalpine woodlands, climate modelling predicts extinction by 2085 (Jungalwalla 2010)	High
Mountain Skink <i>Niveoscincus oryocryptus</i>	Alpine and subalpine	Occurs in rocky outcrops and alpine heathland, climate modelling predicts extinction by 2085 (Jungalwalla 2009)	High
Pedra Branca Skink <i>Niveoscincus palfreymani</i>	Offshore islands	Restricted to tiny islet of Pedra Branca off the south coast of Tasmania. Likely to be an impact of greater storm surges sweeping island although species already tolerates occasional wave sweeping island. Single small population of species indicates High risk.	High

Priority taxa	Principal habitat	Risk factors	Risk Ranking
Fish			
Pedder Galaxias <i>Galaxias pedderensis</i>	Translocated populations Lake Oberon and Strathgordon water supply dam	Originally occurred in the original Lake Pedder and in streams and swampy pools around the lake, now extinct in its natural habitat due to inundation and competition and predation from Brown Trout and the native Climbing Galaxias (<i>Galaxias brevipinnis</i>). Species survives in two translocated breeding populations in Lake Oberon and in the Strathgordon water supply dam. Both waterbodies are deep and permanent, effects of warmer drier climate likely to be relatively minor, however species remains vulnerable due to limited number of populations and limited total abundance.	Medium
Clarence Galaxias <i>Galaxias johnstoni</i>	Freshwater lakes, rivers and other wetlands: Central Plateau	Occupies high altitude lake, marsh and stream habitat. Restricted to the south-eastern Central Plateau, Central Tasmania, including the Nive, Clarence and Little River sub-catchments. Eight known populations, the largest population found in Clarence Lagoon. Minimal capacity to disperse to new habitat. Lake habitat including Clarence Lagoon is shallow and poorly connected and all habitat streams are upper catchment with poor connectivity and low groundwater input (P. Davies pers. comm.). Very high risk of extinction.	High
Western Paragalaxias <i>Paragalaxius julianus</i>	Freshwater lakes, rivers and other wetlands: Central Plateau	Known only from lakes in the Western Lakes area, Central Plateau. Minimal capacity to disperse to new habitat, high risk of extinction.	High
Swamp Galaxias <i>Galaxias parvus</i>	Buttongrass moorland	In moorland swamps and streams in Serpentine and Gordon River catchments, range drastically reduced due to inundation of catchments for hydroelectric power (TSS 2006). Increased drying of small moorland streams and swamps in summer may increase risk of extinction.	High
Maugean Skate <i>Zearaja maugeana</i>	Estuaries	Restricted to Bathurst Harbour (rare) and Macquarie Harbour (relatively common) (Edgar et al. 1999, 2007). Impacts on the Port Davey-Bathurst Harbour estuary likely to be severe with potential disruption of entire system, Maugean Skate in Macquarie Harbour may be more resilient (N. Barrett pers. comm.).	Medium

Table 5. Priority species of marine and coastal mammals and birds which breed within the TWWHA and assessment of risk from climate change based on distribution in the TWWHA, level of philopatry, nesting and breeding habitat and risk from sea-level rise and increased storm surge.

Priority taxa	Locations in TWWHA ¹	Philopatry	Nesting and breeding habitats ¹ , flexibility and risk from inundation and storm surge	Risk Ranking
Mammals				
New Zealand Fur Seal <i>Arctocephalus forsteri</i>	In Australia, breeds on islands in the Maatsuyker Group in the TWWHA	Moderate	Low lying islands, some flexibility in shifting locations for breeding.	Low
Southern Elephant Seal <i>Mirounga leonina</i>	Occasionally recorded breeding on islands in the Maatsuyker Group	Moderate	Restricted locations, flat areas, on black sand or cobbles, limited flexibility in shifting locations for breeding.	Medium
Marine birds				
Shy Albatross <i>Thalassarche cauta</i>	More than half (66%) of global breeding population occurs in TWWHA, on Pedra Branca and Mewstone Island	Very high	Pedra Branca relatively low-lying (max. 60 m) and vulnerable to increased storm surge, Mewstone higher and higher nesting sites lower risk. This species was not considered to be sensitive to the effects of climate change within the marine habitat based on changes in marine productivity within the species' breeding ground (Garnett et al. 2013).	Medium
Australasian Gannet <i>Morus serrator</i>	Nesting on Pedra Branca and Eddystone Rock	Moderate	Pedra Branca and Eddystone relatively low-lying (maximum height: 60 m and 30 m respectively) both vulnerable to increased storm surge, moderate philopatry means some potential to shift nesting locations.	Medium
Little Penguin <i>Eudyptula minor</i>	Numerous nesting locations along coast and offshore islands	Very low	Wide variety of nesting habitats including rock crevices and deep burrows in sand and beneath vegetation, philopatric potential to shift nesting locations.	Low

Priority taxa	Locations in TWWHA ¹	Philopatry	Nesting and breeding habitats ¹ , flexibility and risk from inundation and storm surge	Risk Ranking
Soft-Plumaged Petrel <i>Pterodroma mollis</i>	Has been recorded breeding on Maatsuyker Island	Low	Does not breed close to shores, some flexibility to shift nesting locations. Note that Garnett et al. (2013) ranked species as sensitive to the effects of climate change within the marine habitat due to declines in the marine productivity within breeding range.	Medium
Short-Tailed Shearwater <i>Ardenna tenuirostris</i>	Numerous nesting locations along coast and offshore islands	Very high	Wide variety of nesting habitats where suitable soils depth, highly philopatric, however very flexible in nesting habitats and high potential to shift locations.	Low
Sooty Shearwater <i>Ardenna griseus</i>	Occasional nesting in TWWHA	Very high	Nests intermixed with Short-tailed Shearwater, risks as above.	Low
Fairy Prion <i>Pachyptila turtur</i>	Nesting on numerous offshore islands	High	Wide variety of nesting habitat including rock crevices and burrows, philopatric. Note that Garnett et al. (2013) ranked species as sensitive to the effects of climate change within the marine habitat.	Low
Common Diving-Petrel <i>Pelecanoides urinatrix</i>	Similar locations to Fairy Prion and frequently nest together	High	Wide variety of nesting habitat including rock crevices and burrows, flexible in nesting habitats and some potential to shift locations.	Low
Pacific Gull <i>Larus pacificus</i>	Numerous locations on coast and offshore islands	Moderate - High	Nest in elevated sites, rocky outcrops, headlands, small hillocks, ridges, cliffs and islands, flexible in nesting habitats and some potential to shift locations. Also occasionally nest on lower-lying coastal areas. Generalist species, breeding habitat unlikely to alter substantially. Unknown numbers of Pacific Gulls nesting in TWWHA.	Low
Silver Gull <i>Chroicocephalus novaehollandiae</i>	Numerous locations on coast and offshore islands	Low - Moderate	Very wide range of nesting habitats including elevated sites, flexible in nesting habitats and high potential to shift locations. Birds will abandon colonies and are capable of using more than one colony in a season. Generalist species, breeding habitat unlikely to alter substantially	Low

Priority taxa	Locations in TWWHA ¹	Philopatry	Nesting and breeding habitats ¹ , flexibility and risk from inundation and storm surge	Risk Ranking
Sooty Oystercatcher <i>Haematopus fuliginosus</i>	Numerous nesting locations on offshore islands and rocky foreshores	High	Coastal obligate species, requires rocky foreshores, rock stacks etc to nest and feed; existing nesting habitat likely to be inundated; however, likely that comparable habitat will be able to reform inland due to the absence of constraining factors along the TWWHA coastline. This species rated as High risk at the national level (Garnett et al. 2013).	Medium
Australian Pied Oystercatcher <i>Haematopus longirostris</i>	Small number of nesting records on sandy beaches based on limited survey effort. Likely to have substantial numbers breeding on sandy beaches.	High	Breed on ocean beaches, usually just above the high water mark. Coastal obligate species, requires sandy beaches, shingle or shell-grit areas to nest and feed; existing nesting habitat likely to be inundated; however, likely that comparable habitat will be able to reform inland due to the absence of constraining factors along the TWWHA coastline. This species rated as High risk at the national level (Garnett et al. 2013).	Medium
Caspian Tern <i>Sterna caspia</i>	Occasional nesting records on offshore islands. Birds likely to be nesting in TWWHA.	High	Nesting preference for small offshore islands, nests adjacent to shoreline and on rock stacks; some existing nesting habitat likely to be inundated; however, likely that comparable habitat will be able to reform inland due to the absence of constraining factors along the TWWHA coastline.	Medium
Fairy Tern <i>Sternula nereis</i>	Few birds likely to be nesting in TWWHA (but limited survey effort). Breeding confirmed at one location (Eric Woehler pers. comm.).	High	Coastal obligate species, requires sandy beaches, shingle or shell-grit areas to nest and feed; existing nesting habitat likely to be inundated; however, likely that comparable habitat will be able to reform inland due to the absence of constraining factors along the TWWHA coastline. This species rated as High risk at the national level (Garnett et al. 2013).	Medium
Little Tern <i>Sternula albifrons</i>	Few birds likely to be nesting in TWWHA (Eric Woehler pers. comm.).	High	Coastal obligate species, requires sandy beaches, shingle or shell-grit areas to nest and feed; existing nesting habitat likely to be inundated; however, likely that comparable habitat will be able to reform inland due to the absence of constraining factors along the TWWHA coastline. This species rated as High risk at the national level (Garnett et al. 2013).	Medium

Priority taxa	Locations in TWWHA ¹	Philopatry	Nesting and breeding habitats ¹ , flexibility and risk from inundation and storm surge	Risk Ranking
Crested Tern <i>Thalasseus bergii</i>	Birds likely to be nesting in TWWHA (Eric Woehler pers. comm.).	Moderate	Coastal obligate species, requires shingle or shell-grit areas (vegetated or unvegetated) to nest and feed; existing nesting habitat likely to be inundated; however, likely that comparable habitat will be able to reform inland due to the absence of constraining factors along the TWWHA coastline.	Medium
Black-faced Cormorant <i>Phalacrocorax fuscescens</i>	Australia's only 'true' oceanic cormorant, occasional nesting records on islands and coastal foreshore.	High	Nesting usually close to sea level but some localities on cliffs, 20-40 m above sea level.	Medium
Coastal birds				
Red-Capped Plover <i>Charadrius ruficapillus</i>	Sandy beaches, shell grit and small pebble foreshores.	High	Coastal species, requires sandy beaches to nest and feed; some nesting inland away from coast; some existing nesting habitat likely to be inundated; however, likely that comparable habitat will be able to reform inland due to the absence of constraining factors along the TWWHA coastline. This species rated as High risk at the national level (Garnett et al. 2013).	Medium
Black-Fronted Dotterel <i>Euseyornis melanops</i>	Unknown, forages on muddy perimeters of ponds and lagoons, wetlands, creeks etc.	High	Unknown status in TWWHA – likely to have small breeding population, associated with ponds and pools of groundwater to nest and feed; some breeding habitat may be lost with sea-level rise.	Low
Little Pied Cormorant <i>Microcarbo melanoleucos</i>	Freshwater habitats – lagoons and streams, lakes etc.	Moderate	Nests in trees, occasional ground nesting.	Low
Little Black Cormorant <i>Phalacrocorax sulcirostris</i>	Coastal, marine and freshwater habitats.		Nests in trees.	Low

Priority taxa	Locations in TWWHA¹	Philopatry	Nesting and breeding habitats¹, flexibility and risk from inundation and storm surge	Risk Ranking
Great Cormorant <i>Phalacrocorax carbo</i>	Coastal, marine and freshwater habitats.	Moderate	Nests in trees.	Low
Hooded Plover <i>Thinornis rubricollis</i>	Sandy oceanic beaches.	High	Coastal obligate species, requires sandy beaches to nest and feed; existing nesting habitat likely to be inundated; however, likely that comparable habitat will be able to reform inland due to the absence of constraining factors along the TWWHA coastline. This species rated as High risk at the national level (Garnett et al. 2013).	Medium

¹ From Brothers et al. (2001).

Table 6. Climate change risk assessment for World Heritage fauna values and exemplar taxa listed under natural criterion (i) outstanding examples representing the major stages of the earth's evolutionary history (Anon 1989).

Values Exemplar taxa	Notes	Risk Ranking
Relict biota which show links to ancient Gondwanan biota:	A significant proportion of taxa with ancient Gondwanan links occur in high risk habitats, notably highland rivers, streams and lakes, buttongrass moorland, alpine habitats and caves.	High
Monotremes:		
Platypus <i>Ornithorhynchus anatinus</i>	Species found in a wide range of habitats (Appendix 1) including habitats rated as Low or Medium risk from climate change, likely some changes in distribution and or abundance, low risk of extinction in TWWHA and elsewhere.	Low
Short-beaked Echidna <i>Tachyglossus aculeatus</i>	Species found in wide range of habitats (Appendix 1) including habitats rated as Low or Medium risk, likely some changes in distribution and or abundance, low risk of extinction in TWWHA and elsewhere.	Low
Dasyurid species:		
Spotted-tailed Quoll <i>Dasyurus maculatus</i>	Species found in wide range of habitats (Appendix 1) including habitats rated as Low or Medium risk, likely some changes in distribution and or abundance, low risk of extinction in TWWHA and elsewhere.	Low
Eastern Quoll <i>Dasyurus viverrinus</i>	Species found in wide range of habitats (Appendix 1) including habitats rated as Low or Medium risk, likely some changes in distribution and or abundance, low risk of extinction in TWWHA and elsewhere.	Low
Tasmanian Devil <i>Sarcophilus harrisii</i>	Species found in wide range of habitats (Appendix 1) including habitats rated as Low or Medium risk, species listed as Endangered due to Devil facial Tumour Disease, impacts of climate change on DFTD unknown.	Medium

Values	Notes	Risk Ranking
Exemplar taxa		
Parrots:		
Orange-bellied Parrot <i>Neophema chrysogaster</i>	See Table 4	High
Ground Parrot <i>Pezoporus wallicus</i>	See Table 4	Medium
Frogs:		
Tasmanian froglet <i>Crinia tasmaniensis</i>	The Tasmanian froglet occurred historically in a variety of habitats across much of Tasmania though its range appears to have contracted significantly; currently it appears to be mostly distributed in a range of habitats in the south and west of Tasmania primarily within the TWWHA (Wilson 2010); some reduction in range likely particularly in Central Plateau area.	Medium
Brown froglet <i>Crinia signifera</i>	Species widespread around Tasmania, some reduction in range likely particularly in Central Plateau, low risk of extinction in TWWHA and elsewhere.	Low
Tasmanian Tree Frog <i>Litoria burrowsae</i>	See Table 4	High
Brown Tree Frog <i>Litoria ewingi</i>	Species widespread around Tasmania, some reduction in range likely particularly in Central Plateau, low risk of extinction in TWWHA and elsewhere.	Low
Tasmanian Cave Spider <i>Hickmania troglodytes</i>	Occurs both within caves, at cave entrances and in surface habitats; may be impacted by changes to cave dryness, however widespread in caves around Tasmania including in the TWWHA low risk of extinction.	Low

Values	Notes	Risk Ranking
Exemplar taxa		
Aquatic insect groups with close affinities to groups found in South America, New Zealand and southern Africa: Odonata (dragonflies), Plecoptera (stoneflies), Trichoptera (caddisflies), Ephemeroptera (mayflies), Chironomidae (chironomid midges)	Within this value, freshwater habitats, and in particular highland rivers, streams and lakes and buttongrass moorland streams and pools, rated as High risk from climate change.	High
Crustaceans:		
Anaspidacea	See entry below	
Parastacidae	Up to 15 species of Parastacidae, range of habitats including moorland and rainforest, moorland species, may be some impacts of increased summer dryness on species restricted to buttongrass moorland habitat.	Medium
Primitive taxa showing links to fauna more ancient than Gondwana:	A significant proportion of taxa with ancient Pangean links occur in higher risk habitats, notably highland rivers, streams and lakes, buttongrass moorland, alpine habitats and caves	High
Anaspids:		
Hickman's Pygmy Shrimp <i>Allanaspides hickmani</i>	Living fossil taxa with ancient Pangean and Gondwanan links, severely restricted range in Serpentine and Gordon catchments, restricted to pools in buttongrass moorland, may be impacted by increased drying out of buttongrass moorland pools during summer, combination of restricted range, total reliance on pools in buttongrass moorland and potential for habitat drying out over critical summer period warrants ranking as High risk.	High
Marsh Pygmy Shrimp <i>Allanaspides helonomus</i>	Living fossil taxa with ancient Pangean and Gondwanan links, occurs in pools in buttongrass moorland and in Lake Pedder in Serpentine and Gordon catchments, similar threats to <i>A. hickmani</i> however less likelihood of extinction as occurs over large range including several subcatchments and a small population occurs in Lake Pedder.	Medium

Values Exemplar taxa	Notes	Risk Ranking
Mountain Shrimp <i>Anaspides spinulae</i>	Known from waters below 3 m depth in Lake St Clair and nearby Clarence Lagoon on the Central Plateau; impacts of climate change on Lake St Clair may be limited by depth and size of lake, Clarence Lagoon population may be more at risk, low risk of extinction.	Low
Mountain Shrimp <i>Anaspides tasmaniae</i>	Widespread throughout central, southern and western Tasmania in a range of habitats including subalpine pools, highland lakes, small upland streams, and caves; likely some changes in distribution and or abundance particularly highland freshwater habitats, low risk of extinction in TWWHA and elsewhere.	Low
<i>Trogloneta</i> (a mysmenid spider)	Known from Kutikina Cave on the Franklin River, risk to cave habitats rated as Medium, species may be at risk.	Medium
Species of alpine moths in the subfamily Archiearinae: <i>Pencil Pine Moth</i> <i>Dirce aesiodora</i>	Lives in conifer rainforests at high altitudes wherever the endemic pencil pine (<i>Athrotaxis cupressoides</i>) occurs, now delisted as more widespread than first believed, high risk of extinction.	High
<i>D. lunaris</i>	Species dependent upon <i>Epacris</i> at high elevation, alpine <i>Epacris</i> spp. relatively resilient, low risk of extinction	Low
<i>D. solaris</i>	Species dependent upon <i>Epacris</i> at high elevation, alpine <i>Epacris</i> spp. relatively resilient, low risk of extinction	Low
<i>D. oriplancta</i>	Species is closely linked to coniferous heathland, high risk of extinction.	High
Species in the genus <i>Sabatinca</i> of the primitive lepidopteran sub-order Zeugloptera	Species depend on perennially very damp environments with high concentration of liverworts and access to fern sori as adult food	Medium

Table 7. Climate change risk assessment for World Heritage fauna values and exemplar taxa listed under natural criterion (ii) outstanding examples representing significant ongoing geological processes, biological evolution and man’s interaction with his natural environment (Anon 1989).

Values Exemplar taxa	Notes	Risk Ranking
Endemic members of invertebrate groups.	Habitats rated as higher risk from climate change, notably highland rivers, streams and lakes and alpine habitats, have high levels of fauna endemism	High
Invertebrate species in isolated environments, especially mountain peaks, offshore islands and caves with high levels of genetic and phenotypic variation.	Alpine habitats rated as high risk from climate change, other habitats at lower risk	Medium
Invertebrates of unusually large size:	Exemplar species all rated a low risk of extinction	Low
Giant Pandini Moth <i>Proditrix</i> sp	Occurs in rainforest on giant heath <i>Richea pandanifolia</i> , likely impacts on distribution and abundance, risk of extinction low	Low
Several species of Neanuridae (Collembola)	Occur in rotting logs in rainforest, likely impacts on distribution and abundance, risk of extinction low	Low
Brightly coloured stonefly <i>Eusthenia spectabilis</i>	Occurs in cold streams including the Franklin River, likely impacts on distribution and abundance, risk of extinction low	Low
Invertebrate groups which show extraordinary diversity: land flatworms, large amphipods, Peripatus, Stag beetles, Stoneflies	Exemplar taxa vary in habitat risk, only those restricted to habitats at high risk likely to be impacted (e.g. amphipods in coastal areas)	Indeterminate
Skinks in the genus <i>Niveoscincus</i> which demonstrate adaptive radiation in alpine heaths and boulder fields on mountain ranges	All three species at high risk of extinction from climate change (see species entries in Table 4)	High

Values Exemplar taxa	Notes	Risk Ranking
Value: examples of evolution in mainland mammals (e.g. sub-species of Bennett's wallaby - <i>Macropus rufogriseus</i> , swamp antechinus - <i>Antechinus minimus</i> , southern brown bandicoot - <i>Isodon obesulus</i> , common wombat - <i>Vombatus ursinus</i> , common ringtail possum - <i>Trichosurus vulpecula</i> , eastern pygmy possum - <i>Cercartetus nanus</i> , the swamp rat - <i>Rattus lutreolus</i>) in many birds (e.g. the azure kingfisher - <i>Alcedo azurea</i>) and in island faunas.	Only one exemplar species (Swamp Antechinus) listed as a priority species with low risk of extinction	Low
Value: animal and bird species whose habitat elsewhere is under threat:	Three of the exemplar species listed as Medium risk	Medium
Spotted-tailed quoll <i>Dasyurus maculatus</i>	See entry under criterion (i), above	Low
Swamp antechinus <i>Antechinus minimus</i>	See Table 4	Medium
Broad-toothed rat <i>Mastacomys fuscus</i>	See Table 4	Medium
Ground parrot <i>Pezoporus wallicus</i>	See Table 4	Medium

Table 8. Climate change risk assessment for natural criterion (iii) Superlative natural phenomena, formations or features (Anon 1989).

Value	Notes	Risk Ranking
Glow-worm displays	Glow-worm displays are created by the larvae of the fly <i>Arachnocampa tasmaniensis</i> . Driessen (2010) found an influence of increased levels of cave dryness on variation in glow-worm displays in Mystery Creek Cave. Effect of climate change on caves difficult to predict, but may be an increase in seasonal variation in humidity in some caves (Sharples 2010).	Medium
Bathurst Harbour sessile invertebrate communities	(Not included under original nomination, however Bathurst Harbour supports a range of globally unique sessile invertebrate communities which are likely to fulfil the criteria for superlative natural phenomena. Estuarine habitat rated as High risk.	High

Table 9. Climate change risk assessment for natural criterion (iv) contains the most important and significant habitats where threatened species of plants and animals of outstanding universal value from the point of view of science and conservation still survive (Anon 1989).

Values	Notes	Risk Ranking
Animal species of conservation significance, such as:		
Spotted-tail Quoll <i>Dasyurus maculatus</i>	See entry under criterion (i), above	Low
Swamp Antechinus <i>Antechinus minimus</i>	See Table 4	Medium
Broad-toothed Rat <i>Mastacomys fuscus</i>	See Table 4	Medium
Ground Parrot <i>Pezoporus wallicus</i>	See Table 4	Medium
Orange-bellied Parrot <i>Neophema chrysogaster</i>	See Table 4	High
Pedder Galaxias <i>Galaxias pedderensis</i>	See Table 4	Medium
Pedra Branca Skink <i>Niveoscincus palfreymani</i>	See Table 4	High

Table 10. Threatened vertebrates and invertebrates in the TWWHA and risk for each species from climate change. TTSPA = Tasmanian *Threatened Species Protection Act 1995*.

Species	TTSPA	Risk factors	Risk Ranking
Vertebrates			
Tasmanian Devil <i>Sarcophilus harrisii</i>	En	See Table 6	Medium
Spotted-tailed Quoll <i>Dasyurus maculatus maculates</i>	R	See Table 6	Low
New Zealand Fur Seal <i>Arctocephalus forsteri</i>	R	See Table 5	Low
Southern Elephant Seal <i>Mirounga leonina</i>	En	See Table 5	Medium
Grey Goshawk <i>Accipiter novaehollandiae</i>	En	Nests in mature wet forest, usually in the vicinity of a watercourse or river, forages in a wide range of forest and woodland habitats; currently less than 110 breeding pairs in Tasmania, most nests located in the north and west of the state including the TWWHA. Risks to nesting habitat moderate, changes in distribution and abundance possible.	Low
White-bellied Sea Eagle <i>Haliaeetus leucogaster</i>	V	Nests in patches of mature forest, usually on the coast, also on cliffs, most nests within 5 km of the coast or a large estuary. Forages on a range of prey including fish, birds, mammals and carrion. Risks to nesting habitat moderate, changes in distribution and abundance possible due to impacts of climate change on prey abundance and distribution.	Low
Wedge-tailed Eagle <i>Aquila audax</i>	En	Nests in patches of mature forest, forages in a wide range of forest and open habitats including TWWHA; currently less than 1000 mature adults in Tasmania. Risks to nesting habitat moderate, changes in distribution and abundance possible.	Low

Species	TTSPA	Risk factors	Risk Ranking
Masked Owl <i>Tyto novaehollandiae</i>	En	Nests in hollows in patches of old-growth forests, hunts over a wide range of habitats including cleared land. Impacts on nesting habitat likely to be minor. Some changes in distribution and abundance possible due to changes in distribution and abundance of prey.	Low
Azure Kingfisher <i>Ceyx azureus</i>	En	Nests in riparian wet forest along major rivers including those in the TWWHA. Estimated to be less than 250 birds remaining. Impacts on nesting wet forest habitat likely to be minor, impacts on major lowland rivers also likely to be relatively minor.	Low
Swift Parrot <i>Lathamus discolor</i>	En	Breeding habitat includes Tasmanian blue gum forest (foraging) and old-growth eucalypt forest (nesting habitat) in south-eastern, eastern and north-western Tasmania, post-breeding birds forage on flowering eucalypts (dry and wet forest) in TWWHA. Risks to foraging habitat in TWWHA relatively low, may be some impacts from changed phenology of flowering. Note that this species is listed as highly exposed over its full range to either a loss of climate space or a reduction in climatic suitability by Garnett et al. (2013).	Low
Orange-bellied Parrot <i>Neophema chrysogaster</i>	En	See Table 4	High
Great Crested Grebe <i>Podiceps cristatus</i>	R	Occurs in freshwater lakes and estuarine environments, breeds vegetated lakes.	Medium
Fairy Tern <i>Sterna nereis</i>	R	Occurs in coastal freshwater lakes, wetlands and estuarine environments, nests sandy beaches	Medium
Little Tern <i>Sternula albifrons</i>	En	See Table 5	Medium
Fairy Prion <i>Pachyptila turtur</i>	En	See Table 5	Low
Wilson's Storm-Petrel <i>Oceanites oceanites</i>	R	Pelagic feeder over coastal waters, only occasionally recorded in TWWHA.	Low

Species	TTSPA	Risk factors	Risk Ranking
Soft-Plumaged Petrel <i>Pterodroma mollis</i>	En	See Table 5	Medium
Shy Albatross <i>Thalassarche cauta</i>	V	See Table 5	Medium
Tussock Skink <i>Pseudemoia pagenstecheri</i>	V	Occurs in native grasslands, likely to be present in highland grassland areas of the TWWHA. May be significant impacts on the highland grassland habitat of the species, however species also occurs in lowland native grassland and overall impacts on species likely to be relatively minor.	Medium
Pedra Branca Skink <i>Niveoscincus palfreymani</i>	V	See Table 4	High
Clarence Galaxias <i>Galaxias johnstoni</i>	En	See Table 4	High
Swamp Galaxias <i>Galaxias parvus</i>	R	See Table 4	High
Western Paragalaxias <i>Paragalaxius julianus</i>	R	See Table 4	High
Pedder Galaxias <i>Galaxias pedderensis</i>	En	See Table 4	Medium
Australian Grayling <i>Prototroctes maraena</i>	V	Found in northern, eastern and western rivers but has so far not been recorded from the south-west. Species migrates between fresh and marine waters, adults live and breed in freshwater rivers, with the larvae being swept downstream into coastal waters. Possibility of significant changes in flow regimes of upper catchment rivers which may disrupt life-cycle.	Medium

Species	TTSPA	Risk factors	Risk Ranking
Maugean Skate <i>Zearaja maugeana</i>	En	See Table 4	Medium
Invertebrates			
Tasmanian Devil tapeworm <i>Dasyurotaenia robusta</i>	R	Impacts likely to be similar to host species, see Table 6.	Medium
Pedder Earthworm <i>Hypolimnus pedderensis</i>	En	Species considered to be extinct (Blakemore 2000)	Extinct
Hickman's Pygmy Shrimp <i>Allanaspides hickmani</i>	R	See Table 6	High
Blind Cave Beetle <i>Goedetrechus mendumae</i>	V	Obligate cave dweller known only from the Ida Bay karst system. Cave habitats ranked as medium risk.	Medium
Slender Cave Beetle <i>Goedetrechus parallelus</i>	V	Known from the Junee-Florentine cave system. Cave habitats ranked as medium risk.	Medium
Mole Creek Cave Beetle <i>Tasmanotrechus cockerilli</i>	R	Obligate cave dweller known only from the Mole Creek karst system. Cave habitats ranked as medium risk.	Medium
Ida Bay Cave Beetle <i>Idacarabus troglodytes</i>	R	Obligate cave dweller known only from the Ida Bay karst system. Cave habitats ranked as medium risk.	Medium
Miena Jewel Beetle <i>Castiarina insculpta</i>	En	Until 2013 this species has been rarely observed. In summer 2013 large numbers of beetles were observed in association with the plant <i>Ozothamnus hookeri</i> around the western shore of Great Lake and further west to Lake Augusta (K. Bonham, pers comm). <i>Ozothamnus hookeri</i> occurs in subalpine heathland and subalpine woodland which are ranked as medium risk.	Medium

Species	TTSPA	Risk factors	Risk Ranking
Lake Fenton Trapdoor Spider <i>Plesiothele fentoni</i>	En	The species is known only from Lake Fenton in the Mount Field National Park, where it occurs in subalpine woodland, and tentatively from the Tarraleah area, where it occurs in tall wet forest. Species may be more widespread in forested habitats (TSMS 2013).	Low
Mole Creek Cave Harvestman <i>Hickmanoxyomma gibbergunyar</i>	R	Obligate cave dweller known only from the Mole Creek karst system. Cave habitats ranked as medium risk.	Medium
Ida Bay Cave Harvestman <i>Hickmanoxyomma cavaticum</i>	R	Obligate cave dweller known only from the Ida Bay karst system. Cave habitats ranked as medium risk.	Medium
Little Six-eyed Spider <i>Olgania excavata</i>	R	<i>Olgania excavata</i> is known only from western and south-western Tasmania, where it has been collected from Kutikina Cave, Cardia Cave and caves in the Bubs Hill karst. Several specimens have also been collected from moss in lowland rainforest in the Gordon River Valley (Rix and Harvey 2010).	Low
Mole Creek Cave Pseudoscorpion <i>Pseudotyranochthonius typhlus</i>	R	Obligate cave dweller known only from the Mole Creek karst system. Cave habitats ranked as medium risk.	Medium
Broad-striped Ghost Moth <i>Fraus latistria</i>	R	Species now delisted, habitat requirements are largely unknown; damp heath and sedge habitat is thought to be the preferred habitat	Unknown
Ptunarra Brown Butterfly <i>Oreixenica ptunarra</i>	V	Occurs in highland <i>Poa</i> grasslands in the eastern Central Plateau, impacts of increased dryness and increased fire on highland grassland habitat difficult to predict but may be relatively low	Low
McCubbins Microcaddisfly <i>Taskiria mccubbini</i>	En	In the family Kokiriidae which has Gondwanan affinities, in runnels or swamps around the Lake Pedder impoundment or the shore of the lake itself, small streams and swamps in buttongrass moorland, may be some impacts of increased summer drying.	Medium

Species	TTSPA	Risk factors	Risk Ranking
<i>Pedder Microcaddisfly</i> <i>Taskiropsyche lacustris</i>	En	In the family Kokiriidae which has Gondwanan affinities, in runnels or swamps around the Lake Pedder impoundment or the shore of the lake itself, small streams and swamps in buttongrass moorland, may be some impacts of increased summer drying.	Medium
<i>Spotted Microcaddisfly</i> <i>Orphninostrichia maculata</i>	R	Recorded from Wedge River, Galignite Creek at Scotts Peak Dam road in buttongrass moorland; widely occurring species in a specialised habitat, likely to be delisted with more survey work (M. Driessen pers. comm.).	Low
<i>Miena Microcaddisfly</i> <i>Oxyethira mienica</i>	R	Recorded from Ouse River near Miena and unnamed creek on Scotts Peak Rd, Central Plateau streams at high risk.	High
Freshwater Snail <i>Hydrobiosella armata</i>	R	Recorded from Mt Wellington area and Huon River tributaries.	Medium

7.0 SUMMARY OF HIGH-RISK HABITATS AND SPECIES

Terrestrial fauna habitats in the TWWHA identified as High risk from climate change include alpine habitats such as coniferous vegetation and *Sphagnum* peatlands, freshwater habitats (wetlands and streams of the Central Plateau, shallow or poorly connected lowland lakes, upper-catchment streams in lowland areas, and lower catchment streams with low levels of connectedness to groundwater), and estuarine systems (Table 11).

Several of the habitats ranked as High risk are characteristic of and find their best expression within the TWWHA, notably highland lakes and streams and alpine habitats such as coniferous heathland and *Sphagnum* peatlands. These habitats are also notable for their exceptionally high levels of endemism (particularly among invertebrates), and the high proportion of taxa which are primitive, relictual or show Gondwanan affinities (Mallick and Driessen 2005). As a result, many of the World Heritage fauna values used to underpin nomination of the area for listing are closely linked to these characteristic TWWHA habitats, and these World Heritage fauna values are also ranked as high risk from the effects of climate change (Table 12). Of particular significance is the globally unique Port Davey-Bathurst Harbour estuarine system. While the majority of sessile invertebrate species of the estuary have not been formally described (and therefore do not appear as priority species in Tables 6, 8 and 9), they are likely to include a very high proportion of endemic taxa which are unique to this unusual estuarine system.

Ten priority vertebrate species and three priority invertebrate species were ranked as High risk from the effects of climate change (Table 13). Four high risk species (3 vertebrate, 1 invertebrate) are associated with habitats in buttongrass moorland including pools, swamps and streams; six species occur in alpine habitats (four vertebrates and two invertebrates); one is a coastal vertebrate (Pedra Branca skink); and two are endemic and threatened galaxias from the Central Plateau (Clarence Galaxias and Western Paragalaxias).

Table 11. Fauna habitats of the TWWHA ranked as High risk from the effects of climate change over the 21st century.

High risk habitats

Estuaries

Central Plateau lakes and other wetlands – shallow and poorly-connected

Central Plateau rivers and streams – low and high groundwater input

Lowland lakes and other wetlands – shallow and poorly-connected

Lowland rivers and streams (upper catchment) – low and high groundwater input

Lowland rivers and streams (lower catchment) – low groundwater input

Alpine coniferous heathland and montane (coniferous) rainforest

Alpine grasslands and non-coniferous heathland

Sphagnum peatland

Table 12. World Heritage fauna values and exemplar taxa used in the listing of the TWWHA which are ranked as High risk from the effects of climate change over the 21st century.

Listing criteria	Fauna values and exemplar species
Natural criterion (i) outstanding examples representing the major stages of the earth's evolutionary history.	<p>Relict biota which show links to ancient Gondwanan biota (exemplar taxa: Orange-bellied Parrot, Tasmanian Tree Frog).</p> <p>Aquatic insect groups with close affinities to groups found in South America and New Zealand.</p> <p>Primitive taxa showing links to fauna more ancient than Gondwana (exemplar taxa: Anaspids: Hickman's Pygmy Shrimp, moths in the subfamily Archiearinae: <i>Dirce aesiodora</i>, <i>D. oriplancta</i>).</p>
Natural criterion (ii) outstanding examples representing significant ongoing geological processes, biological evolution and man's interaction with his natural environment.	<p>Endemic members of invertebrate groups.</p> <p>Skinks in the genus <i>Niveoscincus</i> which demonstrate adaptive radiation in alpine heaths and boulder fields on mountain ranges.</p>
Natural criterion (iii) Superlative natural phenomena, formations or features.	Port Davey-Bathurst Harbour sessile invertebrate communities.
Natural criterion (iv) contains the most important and significant habitats where threatened species of plants and animals of outstanding universal value from the point of view of science and conservation still survive.	Pedra Branca Skink <i>Niveoscincus palfreymani</i> .

Table 13. Priority fauna species of the TWWHA ranked as High risk from the effects of climate change over the 21st century*.

Vertebrates		
Orange-Bellied Parrot	<i>Neophema chrysogaster</i>	Buttongrass moorland/coastal
Tasmanian Tree Frog	<i>Litoria burrowsae</i>	Buttongrass moorland
Moss Froglet	<i>Bryobatrachus nimbus</i>	Subalpine habitats
Northern Snow Skink	<i>Niveoscincus greeni</i>	Alpine habitats
Southern Snow Skink	<i>Niveoscincus microlepidotus</i>	Alpine habitats
Mountain Skink	<i>Niveoscincus orocryptus</i>	Alpine habitats
Pedra Branca Skink	<i>Niveoscincus palfreymani</i>	Coastal habitats
Clarence Galaxias	<i>Galaxias johnstoni</i>	Highland lakes and streams
Western Paragalaxias	<i>Paragalaxius julianus</i>	Highland lakes
Swamp Galaxias	<i>Galaxias parvus</i>	Buttongrass moorland swamps
Invertebrates		
Hickman's Pygmy Shrimp	<i>Allanaspides hickmani</i>	Buttongrass moorland
Pencil Pine Moth	<i>Dirce aesiodora</i>	Alpine coniferous vegetation
Miena Micro-caddisfly	<i>Oxyethira mienica</i>	Highland buttongrass moorland streams

*Only priority species in the TWWHA were subject to risk analyses, and this list is not intended to be an exhaustive list of fauna species at risk from climate change in the TWWHA. Priority fauna species = species with the majority of their range in the TWWHA, species included in the original area for World Heritage listing, and threatened species.

8.0 INVASIVE ANIMALS, DISEASES AND TRANSLOCATIONS

8.1 Integrity of the TWWHA

Inclusion of the TWWHA on the World Heritage List required that the area fulfilled the conditions of integrity outlined in the World Heritage Convention, namely that the area should contain ‘all or most of the key interrelated and interdependent elements in their natural relationships’ (UNESCO 2002). The TWWHA was considered exceptional in its high level of integrity, and in particular the very low levels of infestation by and impacts from invasive animals and diseases (Driessen and Mallick 2003). Climate change can be expected to have profound impacts on the integrity of the TWWHA through shifts in natural processes, changes in distribution of established pests and diseases, and in the introduction of novel invasive species and pathogens. An additional issue related to the integrity of the area is the potential for intentional translocations of native species from other areas including mainland Australia for the purposes of conservation.

8.2 Invasive animals

Invasive animals are considered to be one of the principal threats posed by climate change to natural systems generally and to conservation reserves in particular (Dunlop et al. 2012). Several sources of ‘invasive’ species can be envisioned under the sorts of broad-scale and ecosystem-wide changes projected under climate change.

Native migrants

Climate change is projected to result in fundamental shifts in habitats and ecosystems at both the local and the regional level. As a result, there can be expected to be broad-scale changes in the distributions of species as they attempt to track shifts in their habitat or climatic envelope. The definition of ‘invasive’ would not normally include these native migrants. Nevertheless, there is the potential for native migrant species to resemble invasive species, for example in their potential to significantly alter the structure, interactions and composition of existing natural systems.

The issue of management of native migrant species is extremely difficult. This is in part due to the potentially very large number of species responding in this manner, and the uncertainty regarding the potential implications of native species shifting into new areas which end up supporting their original habitat, or in some cases into completely novel habitats (Dunlop and Brown 2008). The other issue to consider is that a native species shifting its range under an altered climate is in effect attempting to ‘ride out’ or survive the change in climate. Any attempt to manage this broad-scale resorting of species and communities under an altered climate will have to weigh up the potential negative consequences of a species shifting into new areas with the imperative for individual species and entire communities to adapt to the challenges of an altered climate.

For an area such as the TWWHA, it is recommended that the paradigm for management of biodiversity should be changed from ‘how to preserve biodiversity in its current form’ to ‘how to minimise loss’ (see Section 9 for further discussion). With this overarching aim, it is recommended that the first-line response to shifts in native species and the likely realignment of existing natural systems in the TWWHA to an altered climate should be to allow these changes to occur without direct intervention. Direct intervention should be considered only where there is a demonstrable

likelihood for a native migrant to threaten an existing natural value (such as a threatened species) and where there is a reasonable likelihood that intervention can protect that value in the long term.

An apparent example of a climate migrant species is the recent arrival of the Hollow-spined Sea Urchin *Centrostephanus rodgersii*. This species, originally from New South Wales, was first detected in Tasmania in 1978 and is now abundant along the State's east coast, and has recently been collected in Bathurst Channel in the TWWHA (Edgar et al. 2007). This species is an aggregating and habitat-modifying animal with the potential for eliminating macroalgae and sessile invertebrates from reefs (Johnson et al. 2005). Given the demonstrable threat posed by this species to the natural values of the Port-Davey-Bathurst Harbour system, Edgar et al. (2007) recommend ongoing monitoring to track the abundance and distribution of the species in the estuary, and consideration of eradication of this species within sensitive habitat zones.

Novel invasive species: not present in Tasmanian

There are a large number of invasive species which occur on mainland Australia which do not currently occur in Tasmania or in the TWWHA (Mallick and Driessen 2010). Tasmania has remained free of many of these species either through its cooler climate making the State unsuitable for warmer-climate invasive species, through strict quarantine controls, and by virtue of its island status. Under an altered climate, there is the potential for mainland invasive species which are currently excluded from Tasmania due to climatic constraints to spread further south (Dunlop et al. 2012). As a result, current management protocols for preventing the entry of invasive species from mainland Australia and elsewhere are likely to be placed under additional pressure as candidate species for potential spread into Tasmania change with the changing climate.

Novel invasive species: present in Tasmanian but not the TWWHA

Climate change has the potential to make the TWWHA more vulnerable to invasive species already present in Tasmania but not yet recorded in the TWWHA, either through a change in climatic suitability for some invasive species, the degradation of existing habitats making them vulnerable to invasion, and potentially through the development of completely novel habitats.

Mallick and Driessen (2010) list a total of 44 invasive vertebrates which have been recorded from Tasmania, of which 18 species have not been recorded from the TWWHA. Of these only two species were ranked as high risk to the TWWHA, the European Red Fox and European Carp (Mallick and Driessen 2010). The TWWHA is climatically suitable for both these species, and is likely to remain suitable under projected climate change. Prevention of the spread of European Carp into the TWWHA has been through effective quarantine controls and regulation of the State's inland fisheries and this management approach is likely to be effective under projected climate change. Spread of the European Red Fox into the TWWHA is considered to be all but inevitable if the species becomes established in Tasmania, although densities are likely to be lower than projected for the eastern and northern parts of the State (Mallick and Driessen 2010). The impacts of climate change on the spread of the European Red Fox throughout Tasmania and into the TWWHA are not known, but are unlikely to materially change the high level of threat posed by this species to native wildlife.

Mallick and Driessen (2010) did not consider the full list of invasive invertebrates recorded from Tasmania but absent from the TWWHA, and instead considered the risks posed by invertebrates

listed as environmental pests. Of these, the large number of marine pests currently occurring around the eastern and northern coasts of Tasmania was considered to represent a high risk for entry into the TWWHA. The unique Port Davey-Bathurst Harbour system is currently unsuited to many invasive marine pests which occur widely on Tasmania's east coast due to the effect of the dark tannin-rich freshwater halocline. A reduction in the depth and transparency of this halocline due to reduced summer rainfall is likely to open this system to the potential establishment of marine pests already established on the east and north coasts of Tasmania (N. Barrett pers. comm.). Due to the capacity of most of these marine pests to disperse via currents around the State's coasts, their eventual spread into the TWWHA under the projected changes due to a warmer climate is likely to be extremely difficult to prevent.

Invasive species currently in the TWWHA

Climate change is also likely to result in the shift and in some cases expansion of range of invasive species already present in Tasmania and in the TWWHA. Examples of established animal pests which appear to be expanding their range under climate change are rabbits, foxes and wild horses moving into and breeding in alpine areas in the Victorian Alps (Pickering et al. 2004). Table 13 presents a preliminary assessment of the potential impacts of climate change on selected invasive animals in the TWWHA including all species identified as being of Moderate, High or Extreme risk (Mallick and Driessen 2010). The potential impacts of climate change are rated for each species as: threat reduced, no change, or threat increased.

Brown Trout and Rainbow Trout are likely to be heavily impacted under drier and warmer conditions and the risks posed by these two invasive fish may decline under climate change (P. Davies pers. comm.; Table 13). In contrast, Redfin Perch are currently restricted to small areas of the TWWHA, and the risks posed by this species may increase under climate change if extreme rainfall events and flooding lead to breaching of barriers to movement (Table 13). Rabbits have been observed at higher altitudes in the Victorian Alps under warmer and drier conditions (Pickering et al. 2004). Rabbits occur widely in the Central Plateau area of the TWWHA where they can impact on native vegetation and cause soil erosion, and this risk may be exacerbated under the warmer and drier conditions projected for this area. The risk posed by Common Starlings may also increase under climate change, as this highly invasive species has the potential to spread into disturbed areas such as alpine and coastal habitats (Mallick and Driessen 2010). Fallow Deer are rated as Low risk as the species currently occurs only in the eastern section of the Central Plateau Conservation Area within the TWWHA primarily on a seasonal basis (Locke 2007). Fallow Deer are thought to be constrained to the eastern edge of CPCA by climatic (altitudinal) factors (Locke 2002, Mallick and Driessen 2010), and there is therefore the potential for expansion into the TWWHA under the projected warmer and drier climate of the Central Plateau.

8.3 Diseases

Climate change is likely to influence the prevalence and impacts of wildlife diseases presently in the TWWHA and to lead to the emergence of new disease threats (Dunlop and Brown 2008). Philips and Driessen (2008) provide an inventory of current wildlife disease threats in the TWWHA. There have been few wildlife health studies targeting the TWWHA conducted to date. A number of wildlife disease monitoring studies have included the TWWHA and the known status of disease occurrence

within the TWWHA is summarised in the Strategy for Managing Wildlife Diseases in the TWWHA (Philips and Driessen 2008). A risk assessment of established wildlife diseases in the TWWHA scored three diseases as extreme or high risk: Chytridiomycosis, Devil Facial Tumour Disease, and Psittacine Circoviral (Beak and Feather) Disease (Philips and Driessen 2008). A fourth disease, Platypus Mucormycosis, was also identified as requiring research to determine the risk of this disease to platypus. A detailed discussion of the potential implications of climate change for these diseases and for possible new disease threats is outside the scope of the present report. Only the potential implications of climate change for chytrid disease is discussed in detail below.

Chytrid fungus (*Batrachochytrium dendrobatidis*) causes the disease known as chytridiomycosis or chytrid infection in amphibians. Chytridiomycosis can cause sporadic deaths in some frog populations, 100% mortality in other populations, and the disease has been implicated in the extinction of a number of frog species in Australia and elsewhere (Philips et al. 2010). Chytrid fungus has now spread across much of Tasmania, particularly to areas associated with human activities and habitation (Philips et al. 2010). The incidence of chytridiomycosis within the TWWHA is relatively low and the majority of the TWWHA appears to be largely free of the pathogen despite the region providing optimal conditions for the persistence of *B. dendrobatidis* (Pauza et al 2010), though recent surveys have detected the pathogen at a number of TWWHA trailheads and roadside sites (A. Philips pers. comm.).

On a global scale, climate change has been predicted to shift environmental conditions towards the growth optimum of pathogens such as chytrid fungus, which may trigger disease outbreaks (Pounds et al. 2006). Experimental and observational studies have demonstrated that the host–pathogen system is strongly influenced by climatic parameters and thereby potentially affected by climate change (Rodder et al. 2010). However, some studies suggest that predicted anthropogenic climate change may in some cases reduce the geographic range of *B. dendrobatidis* and its potential influence on amphibian biodiversity (Rodder et al. 2010). The principal environmental determinants of chytrid are temperature (preferred range of 4–25°C) and available moisture (Piotrowski et al. 2004; Kriger et al. 2007), and the majority of the TWWHA provides ideal conditions for the pathogen (Murray et al. 2010). Chytrid fungus is more likely to persist in permanent rather than ephemeral waterbodies associated with resident amphibians, particularly where there is year long occupancy, for example overwintering tadpoles. (A. Philips pers. comm.). Overall, the projected warming of the TWWHA is not likely to change the suitability of the area for chytrid, and in some areas suitability may actually increase, while periodic drying of currently permanent waterbodies may render some frog habitats less vulnerable to the spread of the disease (A. Philips pers. comm.).

The potential implications of climate change for chytrid and the individual species of frogs of the TWWHA are difficult to predict. Of the seven frog species occurring in the TWWHA, only the Tasmanian Tree Frog is currently listed as being of known very high risk from chytrid (Philips et al. 2010). The Brown Froglet, Common Froglet and Banjo Frog are rated a low risk, while the risk of chytrid to the Moss Froglet, Tasmanian Froglet and Smooth Froglet is unknown (Philips et al. 2010). The susceptibility of the Tasmanian Tree Frog to chytrid combined with the projected impacts of climate change on this species' primary habitat (buttongrass moorland) indicates that this species may be at very high risk. The other endemic frog species in the TWWHA, the Moss Froglet, although not strictly an alpine, occurs in a very narrow range in cloud forest in subalpine heathland (Mitchell

and Swain 1996) and may be at risk under the drier conditions projected under climate change. However, the susceptibility of this species to chytrid is not known (Philips et al. 2010).

8.4 Translocations

Even under the lower-end of climate-change scenarios it is likely that an increasing number of high-profile species will be placed at risk of extinction, resulting in increasing pressure for *ex situ* conservation and translocations or assisted colonisations (Brereton et al. 1995; Burbidge et al. 2011; Harris et al. 2013). The relatively benign projections for climate change compared to much of mainland Australia coupled with the presence of relatively large areas of natural and reserved habitat such as occurs in the TWWHA suggest that Tasmania may be seen as a logical destination for translocations of mainland species at risk of extinction in their natural range. From the perspective of its World Heritage status, the translocation of non-native species into the TWWHA for the purposes of conservation would be directly contrary to the maintenance of the area's integrity. As a result, any decision to introduce non-native species would have to carefully weigh up the potential advantages of translocation with the disadvantages of intentionally reducing the integrity of the TWWHA (Burbidge et al. 2011; Harris et al. 2013).

The present report advocates a shift in the philosophy underpinning management of reserves from one centred on how to preserve biodiversity as it currently exists to 'how much loss is acceptable' (Dunlop and Brown 2008). Consideration of translocations of species under this approach presupposes an emphasis on a clear and rational objective for any active intervention to preserve single species. Under climate change where the numbers of species facing major change and possible extinction is likely to be very large, the current and often implicit rationale that 'each and every species is too important to lose' ceases to be a practical rationale on which to manage change.

As a result, management actions involving translocations of species into the TWWHA for purposes of conservation will in most instances be undesirable for the following reasons. Firstly, the likelihood of success of translocations and the potential for unintended consequences are notoriously difficult to predict even under stable climatic conditions, and these difficulties will be compounded under climate change where the future condition and health of the target habitat will be themselves difficult to predict (Burbidge et al. 2011). Secondly, the number of species likely to be under threat from climate change is likely to be very large even under the lower end of climate change projections for Australia and Tasmania. Given the complexity and expense in successfully mounting a single species translocation and the inherently low likelihood of success, attempts to preserve biodiversity through single species translocations is likely to provide very poor returns in the context of the magnitude of the biodiversity threat posed by climate change.

Table 14. Selected invasive animals already present in the TWWHA, showing possible alteration in risk rating (ameliorated, same, worsened) under climate change.

Invasive species	Current risk rating	Impact under climate change	Notes
Brown Trout <i>Salmo trutta</i>	Extreme	Reduced	Effects of increasing dryness on freshwater systems likely to be significant for Brown Trout, may be more severely impacted than some native fish species (P. Davies pers. comm.), risk may be significantly reduced.
Redfin Perch <i>Perca fluviatilis</i>	Extreme	Increased	Redfin Perch currently in TWWHA and in adjacent Lake Gordon, increase in extreme rainfall events and or flooding may increase chance of crossing barriers and spread into TWWHA catchments such as Maxwell, Franklin, Denison and Old Rivers (P. Davies pers. comm.).
New Zealand Screw Shell <i>Maoricolpus roseus</i>	Extreme	No change	This species was rated as Extreme by Mallick and Driessen (2010), however recent indications are that under current conditions adult survival may be very low. The effects of climate change on the freshwater halocline may make conditions more suited for this species, and risk a risk rating of Extreme is still appropriate.
Dinoflagellate <i>Gymnodinium catenatum</i>	Extreme	No change	This species was rated as Extreme by Mallick and Driessen (2010), however the identification of this species in core samples may have been erroneous (N. Barrett pers. comm.). The effects of climate change on the freshwater halocline may make conditions more suited for this species, and risk a risk rating of Extreme is still appropriate.
Superb Lyrebird <i>Menura novaehollandiae</i>	High	No change	Occurs in wet forest habitat in eastern part of TWWHA, effects of climate change difficult to predict, no change in risk.
European Wasp <i>Vespula germanica</i>	High	No change	Established widely in the TWWHA, impacts poorly documented, effects of climate change difficult to predict, social hymenopteran species which survive in a range of environments and habitats, may occur at higher altitudes under warmer climate, overall no change in ranking

Invasive species	Current risk rating	Impact under climate change	Notes
Hollow-spined Sea Urchin <i>Centrostephanus rodgersii</i>	High	No change	May be 'climate migrant' spreading through natural means as waters around Tasmania become warmer, existing rating of High already recognises climate change, no change in risk.
Cat <i>Felis catus</i>	Moderate	No change	Established widely in the TWWHA, impacts poorly documented but may be locally significant, effects of climate change difficult to predict, may occur at higher altitudes under warmer climate, overall no change in risk.
Goat <i>Capra hircus</i>	Moderate	No change	Distribution now restricted in TWWHA following eradication of feral herds, effects of climate change difficult to predict, no change in risk.
European Rabbit <i>Oryctolagus cuniculus</i>	Moderate	Increased	Widespread in the Central Plateau area, may be advantaged by drier warmer conditions at higher elevations (Pickering et al. 2004), possibility that risk may increase particularly in Central Plateau area.
Dog <i>Canis lupus familiaris</i>	Moderate	No change	Restricted distribution in TWWHA, dogs have been recorded in highland areas, effects of climate change difficult to predict, no change in risk.
Common Starling <i>Sturnus vulgaris</i>	Moderate	Increased	Highly invasive species colonising disturbed areas, alteration to natural habitats in TWWHA under climate change may create increased opportunities for spread, for example into alpine areas, risk may be increased.
Rainbow Trout <i>Oncorhynchus mykiss</i>	Moderate	Reduced	Effects of increasing dryness on freshwater systems likely to be significant for rainbow trout, may be more severely impacted than some native fish species (P. Davies pers. comm.), risk may be significantly reduced.
Large Earth Bumblebee <i>Bombus terrestris</i>	Moderate	No change	Established widely in the TWWHA, impacts poorly documented, effects of climate change difficult to predict, social hymenopteran species which survive in a wide range of

Invasive species	Current risk rating	Impact under climate change	Notes
Feral Honeybee <i>Apis mellifera</i>	Moderate	No change	<p>environments and habitats, may occur at higher altitudes under warmer climate, overall no change in risk.</p> <p>Established widely in the TWWHA, impacts poorly documented, effects of climate change difficult to predict, social hymenopteran species which survive in a very wide range of environments and habitats, may occur at higher altitudes under warmer climate, overall no change in risk.</p>
Fallow deer <i>Dama dama</i>	Low	Increased	<p>Currently fallow deer populations exist in several areas adjacent to the Central Plateau Conservation Area (CPCA) within the TWWHA, particularly around Liawenee and north-west of Bronte Park. Fallow deer also occur within the CPCA at least on a seasonal basis in the area known as the Nineteen Lagoons and along the Pine River and Nive River valleys (Locke 2007). Species may be constrained to eastern edge of CPCA by climatic (altitudinal) factors, and there is the potential for expansion into the TWWHA under a warmer drier climate.</p>

9.0 MANAGEMENT OF IMPACTS OF CLIMATE CHANGE: OVERARCHING APPROACH

The rate, scale and geographic extent of projected impacts from climate change on biodiversity make this a phenomenon of a much greater magnitude than any other threat (Dunlop et al. 2012). In face of these threats, there is a growing consensus among scientists and policy makers that existing approaches to conserving biodiversity may not be adequate to meet the risks (Dunlop and Brown 2008, Steffen et al. 2009, Dunlop et al. 2012) As Steffen et al. (2009) note, ‘the management objectives for the future aimed at maintaining all species in their present locations and ecosystems in their present composition will no longer be appropriate’. In their analysis of Australia’s response to climate change and threats to biodiversity, Dunlop and Brown (2008) similarly observe that biodiversity conservation in a changing climate will require a re-evaluation of what is being managed and for what purpose. They suggest a paradigm shift is urgently required in the role of managers of reserves from one centred on ‘how to preserve biodiversity’ to ‘how much loss is acceptable’ (Dunlop and Brown 2008). An important consideration in such an approach is that effective planning may well begin with preparing the public and government to accept a fundamental change in the goals of biodiversity management (Dunlop and Brown 2008).

Steffen et al. (2009) suggest that the management priority for conserving biodiversity should be to maintain the provision of ecosystem services through a diversity of well-functioning ecosystems, some of which may have no present-day equivalent. Such a change in management focus would also involve a shift from preservation of individual species (including threatened species) to management approaches that can be demonstrated to be effective for many species without necessarily needing to assess the vulnerability and management needs of individual species. Such approaches may focus on ecological processes (e.g. fire), locations and landscapes rather than on individual species (Prober and Dunlop 2011).

An important corollary of a management approach focussed on minimising loss in conservation areas is the importance of large, undisturbed natural areas with a minimum of additional stressors. It is in such areas that natural systems have the best opportunity to adjust to an altered climate without catastrophic loss of ecosystem services such as maintenance of soils and water quality (Pettorelli 2012). In this context, the TWWHA provides an impressive example of a large, contiguous reserve system with a very high level of legislative protection which is largely free of the most common environmental stressors, notably land clearance, invasive animals and weeds (Anon 1989, Driessen and Mallick 2003).

The overarching position recommended with regard to managing impacts of climate change on the TWWHA fauna rests on the following assumptions:

- Climate change will result in alterations in the range and abundance of multiple species, in fauna habitats, and potentially in entire ecosystems within the TWWHA;
- These changes are ‘locked in’ and there is little justification in attempting to prevent the changes which are now inevitable, while there is an urgent need to reduce greenhouse gas emissions in order to prevent further and more extreme climate change;

- The size and integrity of the TWWHA is such that the area's natural systems have an excellent chance of evolving into a new balance with an altered climate without catastrophic disruption to ecosystem services and function.

Overarching management objectives that flow from the above include the following:

1. The primary objective for management of biodiversity in the TWWHA should be to maintain the current level of protection of the area into the future, regardless of changes to the area's natural systems, habitats, flora and fauna, and the World Heritage values on which the area was originally listed. In light of the projected social and economic costs of climate change and the likelihood for increased pressure on natural resources, this objective may in practice be extremely difficult to achieve.
2. Instigate and pursue a change in the paradigm for management of biodiversity within the TWWHA along the lines advocated by Dunlop and Brown (2008) and others, from one centred on 'how to preserve biodiversity in its current form' to 'how to minimise loss'. Such a change in paradigm will have to be pursued among both land managers, governments and the general public and can be expected to incur significant levels of opposition.
3. A shift in management focus from preservation of individual species including threatened species to management approaches that can be demonstrated to be effective for many species without necessarily needing to assess the vulnerability and management needs of individual species. Such approaches might focus on ecological processes (e.g. fire), defined locations, habitats or whole landscapes rather than on individual species (Prober and Dunlop 2011). However, a species-specific focus may still be relevant under this paradigm, for example where monitoring a species provides an effective means of tracking habitat change (for example keystone species). Demonstrating major changes in single species (particularly high-profile and talismanic species) may also be valuable as means of focussing community attention and concern about the implications of climate change, and as way of gaining general public support for less popular management actions aimed at addressing the impacts of climate change on entire habitats and ecological processes.
4. Continue to use fire management (planned burning) and biosecurity measures as primary conservation management tools within the TWWHA, and modify as required to meet the new demands of climate change.
5. Establish ongoing monitoring of selected high priority native species and habitats and priority invasive species save within the TWWHA to verify the reality and extent of fauna and habitat shifts under climate change and to underpin future management and policy directions for the TWWHA.

Specific management actions for the TWWHA fauna are discussed in more detail in the next section.

10.0 MANAGEMENT ACTIONS

Specific management actions for addressing the potential impacts of climate change on the fauna values of the TWWHA are likely to be limited given the severity and magnitude of projected changes. In the face of this difficulty, a useful starting point is to give priority to management actions which have been shown to be useful under a stable climate (i.e. in the recent past), and consider ways in which these proven approaches might be tailored to address the additional threats posed by climate change. Management actions for fauna in the TWWHA considered in detail include the following:

- Fire management in the TWWHA to address novel threats posed by drier and hotter climate;
- Wider use of biosecurity measures by managers including limiting public access to designated areas to reduce spread of invasive species and disease and raising awareness of the threats from invasive species and pathogens to the WHA Values;
- Establishment of breeding populations of species at risk of extinction;
- Consideration of translocations of species;
- Monitoring, control and removal of invasive species where possible;
- Monitoring wildlife diseases;
- Monitoring of habitats;
- Modelling of future range of native species under climate change;
- Targeted surveys of high-risk species;
- Monitoring of high-risk native species.

10.1 Fire management

Fire management within the TWWHA is a long-standing management activity which has evolved with the changing perceptions and understanding of the area's history and ecology. Planned burns in the TWWHA are conducted each year for the primary purpose of protection of life and property. Ecological burns are also periodically conducted, primarily in large areas of buttongrass moorland to reduce the risk of landscape-scale fires that have the potential to damage fire sensitive vegetation. A number of studies have examined the effect of fire on plants, animals and soils in the buttongrass moorlands of the TWWHA and results of these studies are used to inform and develop prescriptions for planned burns. The use of fire as a management tool in the TWWHA is the logical outcome of the central role played by fire in the ecology of the area, and of the power and flexibility of fire as a human management tool to both protect and enhance the natural values of the area.

It is generally accepted that climate change will lead to an increase in both fire frequency and intensity in the TWWHA (DPIPWE 2010), and that this change will be one of the most far-reaching and potentially destructive impacts on the natural values of the area. The current importance of planned burning in the TWWHA as a management tool to protect assets (including natural assets such as fire-sensitive vegetation) and to reduce the likelihood of catastrophic landscape burns is likely to increase under the drier and warmer conditions projected for the TWWHA.

Recommendation 1: Continue the current primary fire-management policy within the TWWHA of using planned burning to manage habitat and protect life and infrastructure and fire-sensitive habitats such as alpine vegetation, coniferous vegetation and rainforest.

Recommendation 2: Systematically monitor peat dryness in buttongrass moorlands with deep and skeletal soils to track changes in fire risk to allow adaptive management of planned burning, and to compare actual change in fire risk with those predicted under current climate models.

10.2 Limiting public access to designated areas

The temporary quarantining of specific areas from general public access has been employed to only a limited extent within the TWWHA, primarily to limit spread of pathogens such as *Phytophthora*. Under the novel climatic conditions projected for the TWWHA under climate change there is the potential for further spread of *Phytophthora* particularly into higher altitudes (DPIPWE 2010) and an unknown potential for novel plant and animals diseases to become established under a warmer and drier climate. Under these scenarios, the strategic quarantining of areas from general access may become more important as a management tool to protect refuge or other high value sites.

Recommendation 3: As part of a strategic approach to managing the impacts of climate change on the TWWHA, continue to employ a management approach of quarantining areas of the TWWHA as a front-line response to novel threats to the area's natural values, including very large areas where justified by the magnitude, extent and uncertainty of the threat.

10.3 Establishment of *ex-situ* breeding populations

The establishment of *ex-situ* breeding populations, for example in zoos or wildlife parks, is a last resort in the preservation of species under immediate threat of extinction in the wild. Establishing *ex-situ* breeding populations has been used successfully for a number of mammals and birds on mainland Australia, and in Tasmania most recently as part of the Save the Devil Program in response to the spread of Devil Facial Tumour Disease. In the context of climate change, the arguments for and against *ex-situ* breeding populations for critically endangered species are similar to those for and against translocations (see Section 8.4). The approach has been effective in the preservation of single species and can make a significant contribution to preserving high-profile components of biodiversity under relatively benign conditions. An example is the successful translocation of the Pedder Galaxias into two new waterbodies (Lake Oberon and the Strathgordon Water Supply Dam) within the TWWHA prior to the species going extinct in its native habitat (the original Lake Pedder). However, translocations are likely to have only limited scope for addressing threats to species in the context of the multi-species and ecosystem-level threat to biodiversity posed by climate change.

Recommendation 4: Support and develop approaches to managing multi-species and ecosystem level threats to biodiversity within the TWWHA, and only consider single-species management approaches such as *ex-situ* breeding populations to conserve single species when there is a reasonable chance of success and when all other ecosystem level approaches have proved ineffective.

10.4 Translocations of species

See Section 8.4 for a discussion of translocations.

Recommendation 5: Discourage the pursuit of single-species management approaches such as translocations of threatened species into or within the TWWHA, and support and develop alternative approaches to managing multi-species and ecosystem level threats to biodiversity within the TWWHA.

10.5 Monitoring, control and removal of invasive species

There are currently several on-going monitoring programs for invasive species in the TWWHA, including baseline and regular follow-up surveys of invasive species within the Port Davey-Bathurst Harbour estuary (Aquenal 2003, 2011; Edgar et al. 1997), a baseline survey of Fallow Deer in the TWWHA (Locke 2007), and baseline surveys for trout in selected catchments within the TWWHA (Davies et al. 2009). In addition, informal monitoring occurs on an *ad hoc* basis through a passive surveillance network including the general public, scientific specialists and Government agencies working in the area (Mallick and Driessen 2010). Given the uncertainties regarding the impact of climate change on both established and potential novel invasive species in the TWWHA, this passive surveillance network should continue to provide a cost-effective front-line reporting of changes in established invasive species and any novel incursions into the area.

Recommendation 6: Continue to support and utilise the informal passive surveillance network to monitor significant changes in established terrestrial invasive species in the TWWHA, and instigate dedicated survey and or eradication programs for species which appear to be expanding in range under climate change or which pose a threat to a natural value, and for any novel invasive species which pose a significant risk to the area's natural values.

Recommendation 7: Support the recommendations in Edgar et al. (1997) for on-going standardised monitoring of invasive species in the Port Davey-Bathurst Harbour estuary.

10.6 Monitoring wildlife diseases

Climate change has the potential for far-reaching effects on disease expression by altering habitat or by causing physiological changes within native host species. Climate change also has the potential to affect vectors such as mosquitoes, ticks and snails, contributing to the transmission of wildlife disease (Philips and Driessen 2008). The Strategy for Managing Wildlife Diseases in the TWWHA (Philips and Driessen 2008) incorporates a series of management actions dealing with established and potential novel wildlife disease in the TWWHA, while the Tasmanian Chytrid Management Plan (Philips et al. 2010) includes actions in relation to the impacts of Chyrid fungus on the frog fauna of the TWWHA including possible impacts of climate change on the disease.

Recommendation 8: Support the recommendations in Philips et al. (2010) for ongoing monitoring of chytrid and high-risk frog species in the TWWHA.

10.7 Monitoring of habitat parameters

The effects of climate change are likely to occur at the landscape level with major perturbations in multiple species and fauna assemblages within vulnerable habitats. Monitoring of key habitat parameters (e.g. soil depth, dryness, lake depth, river flow dynamics, temperature and oxygenation of freshwater habitats) can provide a useful adjunct to monitoring programs targeting single species or entire fauna assemblages. Given the breadth and complexity of projected changes in fauna and fauna habitats under climate change, monitoring key habitat parameters may in some instances provide a more effective indication of the scale and amplitude of change in fauna species and communities than monitoring programs targeting individual species. Key sites for monitoring would include those habitats ranked as High risk from climate change (Table 11).

Recommendation 9: Support the recommendations in Edgar et al. (1997) for monitoring of key habitat parameters in the Port Davey-Bathurst Harbour estuary including: monitor water temperature using loggers deployed at multiple sites and depths along the Bathurst Channel estuarine cline; seasonal monitoring of temperature, salinity, oxygen concentration and plant nutrients along the Port Davey-Bathurst Harbour estuarine cline through the year at least once every five years.

Recommendation 10: Mt Sprent provides an example of buttongrass moorland ranging from lowland areas to the treeline and provides a potential site for monitoring changes in buttongrass moorland habitat quality over a broad altitudinal range. Mt Sprent has been established as a DPIPWE flora long-term monitoring site with weather stations sited above and below the treeline to assist with investigation of ecotone dynamics (DPIPWE 2012). It is recommended that a project be scoped in conjunction with DPIPWE vegetation monitoring program to examine changes in buttongrass moorland habitat at Mt Sprent, for example fauna habitat features such as peat dryness and hydration of freshwater crayfish burrows.

Recommendation 11: Establish long-term monitoring of the condition (depth and temperature) of freshwater habitats in the TWWHA. Monitoring should be carried out using a system of permanent data loggers established over a broad network of high risk habitats incorporating replicates (e.g. shallow poorly connected highland lakes, lowland upper catchment streams with low groundwater input). It would be an advantage to also sample lower-risk habitats (e.g. deep well connected lakes) for comparative purposes. Monitoring could take the form of initial data collection over a 10-15 year period followed by modelling of long-term changes using this data and climate projections (P. Davies pers. comm.).

10.8 Modelling future ranges of native species

The usefulness of climatic modelling to predict changes in species distributions under an altered climate is heavily dependent on the quality of distribution data available for a species. For the majority of invertebrate species of the TWWHA this data is currently insufficient to underpin attempts to predict distributions. To date there have been only limited attempts to model changes in vertebrate species distributions using climatic modelling, for example alpine skinks (Jungalwalla 2010) and the Broad-toothed Mouse and Swamp Rat (Green et al. 2008). Mechanistic modelling is an alternative modelling approach which uses the physiological and ecological requirements of species

to model their potential range under altered climatic conditions. To date there have been no attempts to employ mechanistic modelling to predict vertebrate species distributions under climate change, although this approach is being attempted for the three alpine skinks recorded from the TWWHA (E. Wapstra pers. comm.). There have also been recent advances in an alternative approach to modelling which combines species distribution models and mechanistic habitat models based on physiological budgets of energy and water to estimate risk of extinction under climate change. This approach is currently being applied to a number of Australian frog species by the Australian Centre for Ecological Analysis and Synthesis (ACEAS) including the Moss Froglet.

Recommendation 12: Conduct climate or mechanistic modelling of future range of the freshwater crayfish *Ombrastacoides leptomerus* which is recommended for long-term monitoring of distributional range (see Recommendation 17).

Recommendation 13: Liaise with the School of Zoology, University of Tasmania on the on-going project for mechanistic modelling of the future distribution of the three alpine skinks occurring in the TWWHA.

Recommendation 14: Modelling is currently being conducted for the Moss Froglet using climate-based (N. Mitchell, ACEAS) and mechanistic (M. Carney, University of Melbourne) approaches, and results should be available late in 2013 (N. Mitchell pers. comm.). It is recommended that DPIPWE liaise closely with ACEAS on this on-going project for climate and mechanistic modelling of potential impacts of climate change on the Moss Froglet.

Recommendation 15: The grasshopper *Kosciuscola tasmanicus* is an alpine specialist which occurs above 1000 m altitude in the western Central Plateau region. The species is a potential candidate for long-term monitoring (see Recommendation 21). It is recommended that a project is scoped to delineate the current altitudinal and distributional range of *K. tasmanicus* to provide baseline data on distribution and to allow modelling of potential future range under climate change.

10.9 Targeted Surveys

Baseline information on species distributions and taxonomy within the TWWHA is an essential starting point from which to examine impacts of climate change. The taxonomy and general habitat requirements of most vertebrates of the TWWHA are relatively well known. However actual targeted surveys and documented distribution records of many vertebrate species are still very patchy over the remoter areas of the TWWHA. An additional constraint is that many records that have been collected are not captured by central electronic databases such as DPIPWE Natural Values Atlas and are therefore not easily or readily available. The survey and documentation of the invertebrates of the TWWHA is extremely limited for most groups, with only a small number of taxa having been well surveyed (Mallick and Driessen 2005). Much of the information available on invertebrates of the TWWHA derives from the series of targeted surveys carried out as part of the Directed Wildlife Research (DWR) and Wilderness Ecosystem Baseline Studies (WEBS) projects in the 1980s and 1990s (Driessen et al. 1998; Smith 1998). These surveys focussed on a small number of groups of interest and generally involved the *ad hoc* survey of particular locations of interest or accessibility rather than systematic or stratified sampling of the TWWHA.

Recommendation 16: It is recommended that a WEBS II program be developed for the TWWHA including stratified and repeatable sampling approaches focussing on key areas and processes at risk from climate change.

10.10 Monitoring of native species

The monitoring of impacts of environmental change including climate change on the distribution or abundance of native species is a mainstay of biodiversity management in conservation reserves (Brown 2009). Ideally, monitoring programs provide information on the nature and extent of change in native species which can then be used to design and instigate a management response to the documented change. In practice, limitations in resources mean that only a small number of potential candidate species are actually monitored, and these species are generally selected on the basis of their high profile or public perceptions of their value for biodiversity.

The monitoring of entire species assemblages in specific habitats and locations is costly and labour intensive, but may be justified for extremely high value habitats such as the Port Davey-Bathurst Harbour estuary. Monitoring single species is also useful as means of directly demonstrating that change is occurring in high risk species, which can be of significant benefit in influencing public opinion on the reality and severity of climate change impacts. The present selection of candidate species for monitoring attempts to cover a range of broader faunal groups and habitats (invertebrates and vertebrates, terrestrial, freshwater and estuarine). The candidate species were also selected based on the practicality of monitoring over the long term (decades) and the availability of practical and cost-effective techniques for monitoring abundance or range. Note that the list of is not intended to be exhaustive of all potential candidate species.

Recommendation 17: Reassess and redesign the Mt Weld-Warra altitudinal transect study to focus on the small number of species (steno-altitudinal, high-altitude specialists) identified as potential indicator species (M. Driessen unpub. data.).

The Mt Weld-Warra altitudinal transect study was established as a long-term program with the aim of recording baseline inventory and distributional data along an altitudinal gradient at the WARRA Long Term Ecological Research (LTER) site against which future changes in the altitudinal distribution of flora and fauna can be measured in relation to climate change (Brown et al. 2001; Doran et al 2003). Analysis of baseline data indicate that, at the ordinal level, pitfall and malaise trapping of invertebrates is subject to very high levels of background variation which will severely limit the use of the program as a tool to monitor shifts in invertebrate fauna composition over a time span of decades (M. Driessen unpub. data.).

Recommendation 18: Support the recommendations in Edgar et al. (1997) for baseline surveys of soft-sediment and reef communities, and for on-going standardised monitoring of native soft-sediment benthic communities, fish species, and reef communities of the Port Davey-Bathurst Harbour estuary.

Recommendation 19: Undertake a baseline survey to map the current distributional edge of the burrowing crayfish *Ombrastacoides leptomerus* and repeat the survey at regular (e.g. 5 year) intervals to track changes in the species distributional edge over time.

The burrowing crayfish *Ombrastacoides leptomerus* has a long eastern boundary in the Central Plateau area, and the species provides an excellent candidate for targeted monitoring of fauna changes in the TWWHA under climate change. Species of the Parastacidae (*Ombrastacoides* and *Spinastacoides*) are high-profile elements of the TWWHA fauna, have significant World Heritage value due to their Gondwanan affinities with species more closely related to New Zealand and Madagascar crayfish than the rest of the Australian fauna, and many of the species occur in habitats at risk from climate change (buttongrass moorland). The burrows themselves also provide a unique aquatic moorland habitat (pholeteros) with a unique invertebrate fauna with high levels of Tasmanian endemism and relictual taxa.

Because the burrows are (relatively) conspicuous it is possible to map the edge of their distribution with some accuracy. Examining the debris at the burrow opening can also give a good indication of whether the burrow is occupied, providing a marker against which a shrinking range can be assessed (A. Richardson pers. comm.). Burrow presence and absence records have been collected for the distributional edge of *O. leptomerus* in the area north of Lake Ida (A. Richardson unpub. data). The distributional edge can be efficiently surveyed by a team criss-crossing the distributional edge and physically or electronically tagging burrow positions and noting their activity.

Recommendation 20: Consider monitoring long-term changes in distribution of the Moss Froglet under climate change

The Moss Froglet is primarily an alpine-subalpine species and is rated a High risk due to its very restricted range and association with damp habitats primarily in heathland. The Moss Froglet is entirely terrestrial in its development, with females depositing small clutches of large eggs in nests built into moss, lichen or peat in a spring–summer breeding season (Rounsevell et al. 1994, Mitchell 2002a). Furthermore, because hatching occurs well in advance of metamorphosis, 9-10 months of development is spent as a free-living but non-feeding tadpole within the capsule fluid retained within the nest (Mitchell and Swain 1996). In captivity, embryos were found to be stunted and experience high mortality under slightly drier conditions than normal (Mitchell 2002b). Incubation temperature also has a profound effect on embryonic development. Development is accelerated at higher temperatures, and in the field this can translate into metamorphosis occurring before rather than the more typical post-summer where temperatures are higher (Mitchell and Seymour 2000).

The above ecological and physiological attributes indicate that the Moss Froglet may be highly vulnerable to increases in temperature and reductions in summer rainfall projected for the TWWHA under climate change. The Moss Froglet is currently being monitored at several sites for impacts of chytrid (A. Philips pers. comm.), and the species is also part of an on-going project applying both climate and mechanistic modelling of potential impacts of climate change to a number of Australian frog species (see Recommendation 14). Preliminary results of climate modelling indicate that the habitat for the Moss Froglet will disappear by 2070 under the A1F1 scenario from the

Intergovernmental Panel on Climate Change's Special Report on Emissions Scenarios (R. Tingley unpub. data).

Adult Moss Froglets are cryptic and are extremely difficult to survey by sight. Long-term monitoring of the distribution of the Moss Froglet could potentially be conducted using remote call loggers used to pick up frog calls. The species has a prolonged call season, calls both day and night, and the absence of calls over an extended period can be a reliable indication of the species' absence (N. Mitchell pers. comm.). Monitoring could be conducted by establishing call box locations at selected sites and populations at highest risk from climate change (as indicated by modelling) and recording calls at 3-5 year intervals.

Recommendation 21: Delineate the current altitudinal and distributional range of the grasshopper *Kosciuscola tasmanicus* to provide baseline data on distribution and to allow modelling of potential future range under climate change (see Recommendation 15). The results from modelling would then determine if this species is suitable for a long-term monitoring program to track changes in the altitudinal range of *K. tasmanicus*.

The *Kosciuscola* grasshoppers are a small group of alpine specialists which are endemic to the south-eastern Australia. There are four mainland species (*K. tristis*, *K. usitatus*, *K. cognatus*, *K. cuneatus*) and the single Tasmanian species (*K. tasmanicus*) (Umbers et al. 2012). The distribution of *K. tasmanicus* occurs above 1000 m over an area of 300 km in the western Central Plateau region including Liaweenee Moor (M. Driessen pers. comm.). The sister species *K. tristis* has received some research attention due to its unusual ability to change colour under different ambient temperatures (Umbers et al. 2012). *Kosciuscola* grasshoppers including *K. tasmanicus* are abundant during the late summer and early autumn months. They can be relatively easily sampled in their grassland and heathland habitat using sweep nets, and there is the potential for direct visual survey along walked transects as the species is relatively easy to identify by sight (M. Driessen pers. comm.).

Recommendation 22: Establish baseline information on nesting locations of coastal bird species at key sites along the TWWHA coastline, and establish ongoing monitoring to track potential changes in coastal nesting habitat and nesting frequency and success.

The principal impact of climate change on the coastal environment will be sea level rise leading ultimately to a landwards shift of coastal processes and landforms including shorelines and dunes (Sharples 2011). This is likely to result in some level of disruption to existing coastal habitats, particularly for some coastal-breeding bird species. The recession of these habitats is predicted to be sufficiently gradual over the next 100 years to allow time for these coastal breeding birds to adjust. Garentt et al. (2013) identified six coastal-breeding bird species (see Section 6.1) at risk at a national level from the potential impacts of climate change. However the exacerbating impacts of coastal development and introduced predators are likely to be minimal along the coastline of the TWWHA. Indeed the TWWHA may become increasingly important for the conservation of these species.

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APPENDIX 1

List of all native vertebrate fauna recorded from the TWWHA¹ showing TWWHA habitats, endemism, distribution and threatened species listing status. Species in **bold** are priority species including: (a) non-marine species with the entirety or majority of range (including breeding range) in the TWWHA; (b) marine mammals and birds which breed on the coast or islands of the TWWHA, (c) World Heritage value species used in listing of TWWHA; and (d) threatened species. Risk rating for climate change impacts is shown for each priority species (see Section 6 for more details).

Common Name	Species	Habitats ²	Endemic ³	Distribution in TWWHA ⁴	Proportion of Tasmanian distribution in TWWHA ⁵	Listing ⁶	Risk
Mammals: Terrestrial							
Swamp Antechinus	<i>Antechinus minimus</i>	Bm Sc_dry Cst_hth	es	w	prim		Medium
Dusky Antechinus	<i>Antechinus swainsonii</i>	Sc-wet (higher alt) Rf	es	w	part		
Tasmanian Bettong	<i>Bettongia gaimardi</i>	Sc_dry	e	r	part		
Little Pygmy Possum	<i>Cercartetus lepidus</i>	Sc_wet/dry/sub.wod		w	part		
Eastern Pygmy Possum	<i>Cercartetus nanus</i>	Rf Sc_wet/dry /sub.wod Bm	es	w	part		
Chocolate Wattled Bat	<i>Chalinolobus morio</i>	Rf, Sc		r	part		
Spotted-tailed Quoll	<i>Dasyurus maculatus maculatus</i>	Rf_ Sc_wet/dry/sub.wod Cst_hth		w	part		Low
Eastern Quoll	<i>Dasyurus viverrinus</i>	Al_grs Sc_wet/dry/sub.wod Bm	e	w	part		Low

Common Name	Species	Habitats ²	Endemic ³	Distribution in TWWHA ⁴	Proportion of Tasmanian distribution in TWWHA ⁵	Listing ⁶	Risk
Tasmanian Pipistrelle	<i>Falsistrellus tasmaniensis</i>			r	part		
Water Rat	<i>Hydromys chrysogaster</i>	FW_len/lot		w	part		
Southern Brown Bandicoot	<i>Isodon obesulus</i>	Sc_dry Bm Cst_hth	es	w	part		
Bennetts Wallaby	<i>Macropus rufogriseus</i>	Al_grs Sc_wet/dry/sub.wod Cst_hth	es	w	part		
Broad-toothed Mouse	<i>Mastacomys fuscus</i>	Bm Sc_subalpine heath	es	w	prim		Medium
Lesser Long-eared Bat	<i>Nyctophilus geoffroyi</i>	Rf, Sc		w	part		
Goulds Long-eared Bat	<i>Nyctophilus timoriensis</i>			r	part		
Platypus	<i>Ornithorhynchus anatinus</i>	Fw_len/lot		w	part		Low
Eastern Barred Bandicoot	<i>Perameles gunnii</i>	Al_grs Sc_sub.wod (grassy)		r	part		
Long-nosed Potoroo	<i>Potorous tridactylus</i>	Sc_dry/wet Cst_hth	es	r	part		
Common Ringtail Possum	<i>Pseudocheirus peregrinus</i>	Rf Sc_wet/dry/sub.wod	es	w	part		
Long-tailed Mouse	<i>Pseudomys higginsi</i>	Rf Sc_wet Bm Scree	e	w	part		

Common Name	Species	Habitats ²	Endemic ³	Distribution in TWWHA ⁴	Proportion of Tasmanian distribution in TWWHA ⁵	Listing ⁶	Risk
Swamp Rat	<i>Rattus lutreolus</i>	RF Sc_wet Bm Cst_hth	es	w	part		
Tasmanian Devil	<i>Sarcophilus harrisii</i>	Rf, Sc, Cst, Bm	e	w	part	En	Medium
White-footed Dunnart	<i>Sminthopsis leucopus</i>	Rf Sc_wet/dry/sub.wod Bm Cst_hth	es	r	part		
Echidna	<i>Tachyglossus aculeatus</i>	Al, Rf, Sc, Bm, Cst	es	w	part		Low
Tasmanian Pademelon	<i>Thylogale billardierii</i>	Rf Sc_wet/dry (wet gullies) Bm	e	w	part		
Brushtail Possum	<i>Trichosurus vulpecula</i>	Rf, Sc, Bm	es	w	part		
Large Forest Eptesicus	<i>Vespadelus darlingtoni</i>	Al, Rf, Sc		r	part		
King Rver Eptesicus	<i>Vespadelus regulus</i>	Sc_wet/dry		r	part		
Little Forest Eptesicus	<i>Vespadelus vulturnus</i>	Sc_wet/dry		r	part		
Wombat	<i>Vombatus ursinus</i>	Al_grs Sc_wet/dry/sub.wod Bm Cst_hth	es	w	part		

Common Name	Species	Habitats ²	Endemic ³	Distribution in TWWHA ⁴	Proportion of Tasmanian distribution in TWWHA ⁵	Listing ⁶	Risk
Mammals: marine							
New Zealand Fur Seal	<i>Arctocephalus forsteri</i>	Ocean waters Offshore islands (breeding, haul out)		r	part	R	Low
Australian Fur Seal	<i>Arctocephalus pusillus</i>	Ocean waters Offshore islands (haul out)		r	part		
Leopard Seal	<i>Hydrurga leptonyx</i>	Ocean waters Offshore islands (haul out)		r	part		
Southern Elephant Seal	<i>Mirounga leonina</i>	Ocean waters Offshore islands (breeding, haul out)		r	part	En	Medium
Birds: terrestrial							
Yellow-Rumped Thornbill	<i>Acanthiza chrysorrhoa</i>	Al_grs Sc_dry/sub.wod	es	r	part		
Tasmanian Thornbill	<i>Acanthiza ewingii</i>	Rf Sc_wet	e	w	part		
Brown Thornbill	<i>Acanthiza pusilla</i>	Rf Sc_wet Bm	es	w	part		
Eastern Spinebill	<i>Acanthorhynchus tenuirostris</i>	Cst_hth Rf Sc_wet/dry Cst_hth	es	w	part		

Common Name	Species	Habitats ²	Endemic ³	Distribution in TWWHA ⁴	Proportion of Tasmanian distribution in TWWHA ⁵	Listing ⁶	Risk
Scrubtit	<i>Acanthornis magnus</i>	Rf Sc_wet	e	w	part		
Collared Sparrowhawk	<i>Accipiter cirrhocephalus</i>	Rf Sc_wet/dry/sub.wod		r	part		
Brown Goshawk	<i>Accipiter fasciatus</i>	Sc_wet/dry/sub.wod		r	part		
Grey Goshawk	<i>Accipiter novaehollandiae</i>	Rf (breed) Sc_wet (breed) Sc_dry (forage)		w	part	En	Low
Australian Owlet-Nightjar	<i>Aegotheles cristatus</i>	Sc_wet/dry	es	r	part		
Azure Kingfisher	<i>Alcedo azurea</i>	Rf Sc_wet	es	r	part		
Little Wattlebird	<i>Anthochaera chrysoptera</i>	Sc_dry Cst_hth	es	r	part		
Yellow Wattlebird	<i>Anthochaera paradoxa</i>	Al_sub.wod Sc_wet/dry/sub.wod	e	w	part		
Richard's Pipit	<i>Anthus australis</i>	Al_grs Sc_dry/sub.wod (open) Bm?bm Cst_grs/sand	es	w	part		
Fork-Tailed Swift	<i>Apus pacificus</i>	aerial		r	part		
Wedge-Tailed Eagle	<i>Aquila audax</i>	Sc_wet (breed) Sc_dry/sub.wod Bm Cst_hth		w	part	En	Low

Common Name	Species	Habitats ²	Endemic ³	Distribution in TWWHA ⁴	Proportion of Tasmanian distribution in TWWHA ⁵	Listing ⁶	Risk
Chestnut Teal	<i>Anas castanea</i>	Wet Cst_mud Est Fw_lot		w	part		
Grey Teal	<i>Anas gibberifrons</i>	Wet Cst_mud Est Fw_lot		w	part		
Australasian Shoveler	<i>Anas rhynchotis</i>	Wet Cst_mud Est Fw_lot		r	part		
Pacific Black Duck	<i>Anas superciliosa</i>	Wet Cst_mud Est Fw_lot		w	part		
Great Egret	<i>Ardea alba</i>	Wet Fw_len Cst_mud		r	part		
Dusky Woodswallow	<i>Artamus cyanopterus</i>	Sc_dry/sub.wod Cst_hth		r	part		
Musk Duck	<i>Biziura lobata</i>	Wet Fw_lot Est		w	part		
Australasian Bittern	<i>Botaurus poiciloptilus</i>	Wet		r	part		
Sulphur-Crested Cockatoo	<i>Cacatua galerita</i>	Rf Sc_wet/dry Bm		w	part		

Common Name	Species	Habitats ²	Endemic ³	Distribution in TWWHA ⁴	Proportion of Tasmanian distribution in TWWHA ⁵	Listing ⁶	Risk
Fan-tailed Cuckoo	<i>Cacomantis flabelliformis</i>	Rf Sc_wet/dry		w	part		
Striated Fieldwren	<i>Calamanthus fuliginosus</i>	Bm Al_hth Cst_hth	es	w	part		
Yellow-tailed Black-Cockatoo	<i>Calyptorhynchus funereus</i>	Rf Sc_wet/dry/sub.wod Cst_hth		w	part		
Australian Wood Duck	<i>Chenonetta jubata</i>	Fw_lot Wet Est		r	part		
Black Swan	<i>Cygnus atratus</i>	Fw_lot Est Wet Cst-mud		w	part		
Horsfield's Bronze-Cuckoo	<i>Chrysococcyx basalus</i>	Sc_dry		r	part		
Shining Bronze-Cuckoo	<i>Chrysococcyx lucidus</i>	Rf Sc_wet/dry		w	part		
Spotted Quail-Thrush	<i>Cinlosoma punctatum</i>	Sc_dry/sub.wod	es	r	part		
Swamp Harrier	<i>Circus aeruginosus</i>	Bm Cst_grs		r	part		
Grey Shrike-Thrush	<i>Colluricincla harmonica</i>	Sc_wet/dry/sub.wod Cst_hth	es	w	part		
Black-Faced Cuckoo-Shrike	<i>Coracina novaehollandiae</i>	Sc_wet/dry	es	w	part		
Forest Raven	<i>Corvus tasmanicus</i>	Al, Sc, Bm, Cst Cst_sand		w	part		

Common Name	Species	Habitats ²	Endemic ³	Distribution in TWWHA ⁴	Proportion of Tasmanian distribution in TWWHA ⁵	Listing ⁶	Risk
Stubble Quail	<i>Coturnix pectoralis</i>	Cst_grs		r	part		
Brown Quail	<i>Coturnix ypsilophora</i>	Al_grs	es	r	part		
		Sc_dry (grassy)					
		Cst_grs/hth					
Grey Butcherbird	<i>Cracticus torquatus</i>	Rf	es	r	part		
		Sc_wet/dry					
		Cst_hth					
Pallid Cuckoo	<i>Cuculus pallidus</i>	Sc_dry		r	part		
White-Faced Heron	<i>Egretta novaehollandiae</i>	Fw_lot		w	part		
		Est					
		Wet					
Brown Falcon	<i>Falco berigora</i>	Al, Rf, Sc, Bm, Cst	es	w	part		
Nankeen Kestrel	<i>Falco cenchroides</i>	Cst_sand/cliffs		r	part		
Australian Hobby	<i>Falco longipennis</i>	Al_grs		r	part		
		Sc_dry (with open areas)					
Peregrine Falcon	<i>Falco peregrinus</i>	Sc_dry (open woodland)		w	part		
		Cst_cliffs					
		Isl					
Eurasian Coot	<i>Fulica atra</i>	Fw_lot		r	part		
		Est					
		Wet					
Latham's Snipe	<i>Gallinago hardwickii</i>	Wet		w	part		
		Bm					
Tasmanian Native-Hen	<i>Gallinula mortierii</i>	Fw_lot/len (margins)	e	r	part		
		Wet					

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Black-Tailed Native Hen	<i>Gallinula ventralis</i>	Wet Fw_lot/len (margins)		r	part		
Tawny-Crowned Honeyeater	<i>Gliciphila melanops</i>	Bm (coastal) Cst_hth	es	r	part		
Australian Magpie	<i>Gymnorhina tibicen</i>	Sc_dry (with open areas)	es	r	part		
White-Bellied Sea-Eagle	<i>Haliaeetus leucogaster</i>	Cst Est Isl Fw_lot (large inland)		w	part		
White-Throated Needletail	<i>Hirundapus caudacutus</i>	Aerial		w	part		
Welcome Swallow	<i>Hirundo neoxena</i>	Sc, Bm, Cst		w	part		
Swift Parrot	<i>Lathamus discolor</i>	Sc_wet/dry		r	part	En	Low
Yellow-Throated Honeyeater	<i>Lichenostomus flavicollis</i>	Sc_wet/dry/sub.wod Cst_hth	e	w	part		
Superb Fairy-Wren	<i>Malurus cyaneus</i>	Sc_wet/dry (with open areas) Bm Cst_hth	es	w	part		
Noisy Miner	<i>Manorina melanocephala</i>	Sc_dry	es	r	part		
Little Grassbird	<i>Megalurus gramineus</i>	Wet	es	r	part		
Dusky Robin	<i>Melanodryas vittata</i>	Sc_dry Cst_hth	e	w	part		
Black-Headed Honeyeater	<i>Melithreptus affinis</i>	Sc_wet/dry/sub.wod Cst_hth	e	w	part		

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Strong-Billed Honeyeater	<i>Melithreptus validirostris</i>	Rf Sc_wet/dry Cst_hth	e	w	part		
Satin Flycatcher	<i>Myiagra cyanoleuca</i>	Sc_wet/dry Cst_hth		r	part		
Orange-Bellied Parrot	<i>Neophema chrysogaster</i>	Bm (breed) Cst_grs/hth/salt Wet		r	prim	En	High
Blue-Winged Parrot	<i>Neophema chrysostoma</i>	Al_grs Sc_dry/sub.wod (grassy) Cst_grs/hth/sand		r	part		
Southern Boobook	<i>Ninox novaeseelandiae</i>	Rf Sc_wet/dry	es	w	part		
Olive Whistler	<i>Pachycephala olivacea</i>	Rf Sc_wet Cst_hth	es	w	part		
Golden Whistler	<i>Pachycephala pectoralis</i>	Rf Sc_wet Cst_hth	es	w	part		
Spotted Pardalote	<i>Pardalotus punctatus</i>	Sc_dry Cst_hth		r	part		
Striated Pardalote	<i>Pardalotus striatus</i>	Sc_wet/dry Cst_hth	es	w	part		
Tree Martin	<i>Petrochelidon nigricans</i>	Sc_dry		w	part		

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Scarlet Robin	<i>Petroica boodang</i>	Sc_dry Cst_grs/hth	es	r	part		
Flame Robin	<i>Petroica phoenicea</i>	Al_grs Sc_wet/dry/sub.wod Cst_grs/hth		w	part		
Pink Robin	<i>Petroica rodinogaster</i>	Rf Sc_wet	es	w	part		
Ground Parrot	<i>Pezoporus wallicus</i>	Bm		w	prim		Medium
Common Bronzewing	<i>Phaps chalcoptera</i>	Sc_wet/dry/sub.wod Cst_hth		r	part		
Brush Bronzewing	<i>Phaps elegans</i>	Sc_wet/dry/sub.wod Cst_hth		w	part		
New Holland Honeyeater	<i>Phylidonyris novaehollandiae</i>	Sc_wet/dry Cst_hth	es	w	part		
Crescent Honeyeater	<i>Phylidonyris pyrrhoptera</i>	Rf Sc_wet/sub.wod Cst_hth		w	part		
Green Rosella	<i>Platycercus caledonicus</i>	Rf, Sc, Bm, Cst	e	w	part		
Eastern Rosella	<i>Platycercus eximius</i>	Sc_dry	es	r	part		
Tawny Frogmouth	<i>Podargus strigoides</i>	Sc_wet/dry Cst_hth		r	part		
Great Crested Grebe	<i>Podiceps cristatus</i>	Fw_lot Est Cst_water		r	part	R	Medium

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Hoary-headed Grebe	<i>Poliiocephalus poliocephalus</i>	Fw_lot Est Cst_water Est		w	part		
Purple Swamphen	<i>Porphyrio porphyrio</i>	Wet Fw_lot/len (margins)		r	part		
Lewin's Rail	<i>Rallus pectoralis</i>	Fw_len (margins) Wet Bm		r	part		
Grey Fantail	<i>Rhipidura albiscapa</i>	Rf, Sc, Bm, Cst	es	w	part		
White-Browed Scrubwren	<i>Sericornis frontalis</i>	Sc_wet Cst_hth	es	w	part		
Beautiful Firetail	<i>Stagonopleura bella</i>	Al_grs/hth Sc_wet/dry/sub.wod Cst_hth		w	part		
Southern Emu-Wren	<i>Stipiturus malachurus</i>	Bm	es	w	prim		Medium
Black Currawong	<i>Strepera fuliginosa</i>	Sc_sub.wod Al_hth Rf, Sc, Cst (winter) Bm	e	w	part		
Grey Currawong	<i>Strepera versicolor</i>	Sc_wet/dry/sub.wod Cst_hth	es	r	part		
Australian Shelduck	<i>Tadorna tadornoides</i>	Fw_lot Est Cst_sand Wet		r	part		

Common Name	Species	Habitats ²	Endemic ³	Distribution in TWWHA ⁴	Proportion of Tasmanian distribution in TWWHA ⁵	Listing ⁶	Risk
Common Greenshank	<i>Tringa nebularia</i>	Cst_mud Est Wet Fw_lot (margins)		r	part		
Masked Owl	<i>Tyto novaehollandiae</i>	Sc_wet/dry	es	r	part		
Masked Lapwing	<i>Vanellus miles</i>	Cst_grs/sand Wet		w	part		
Banded Lapwing	<i>Vanellus tricolor</i>	Cst_grs Wet (dry margins)		r	part		
Bassian Thrush	<i>Zoothera lunulata</i>	Rf Sc_wet Cst_hth		w	part		
Silvereye	<i>Zosterops lateralis</i>	Rf, Sc, Bm, Cst	es	w	part		
Birds: coastal							
Common Sandpiper	<i>Actitis hypoleucos</i>	Wet Fw-len/lot		r	part		
Ruddy Turnstone	<i>Arenaria interpres</i>	Cst_sand/rock/mud Int Cst_sand/rock/mud Wet		r	part		
Red Knot	<i>Calidris canutus</i>	Wet		r	part		
Red-Necked Stint	<i>Calidris ruficollis</i>	Cst_mud/sand Wet Cst_mud/sand FW-lot (shallow lakes)		r	part		

Common Name	Species	Habitats ²	Endemic ³	Distribution in TWWHA ⁴	Proportion of Tasmanian distribution in TWWHA ⁵	Listing ⁶	Risk
Double-Banded Plover	<i>Charadrius bicinctus</i>	Cst_sand/mud Wet		r	part		
Hooded Plover	<i>Thinornis rubricollis</i>	Cst_sand/rock/mud Fw_lot (coastal)		r	part		Medium
Red-Capped Plover	<i>Charadrius ruficapillus</i>	Cst_sand/rock/mud Est Fw_lot (coastal) Wet		r	part		Medium
Black-Fronted Dotterel	<i>Euseyornis melanops</i>	Fw_len/lot (shallow margins) Wet		r	part		Low
Little Pied Cormorant	<i>Phalacrocorax melanoleucos</i>	Cst_water Est Fw_len/lot (small to large, inc. inland)		w	part		Low
Little Black Cormorant	<i>Phalacrocorax sulcirostris</i>	Cst_water Est Fw_len/lot		w	part		Low
Great Cormorant	<i>Phalacrocorax carbo</i>	Fw_lot/len (larger water bodies) Cst_water Est		w	part		Low
Birds: marine							
King Penguin	<i>Aptenodytes patagonicus</i>	Cst_water		r	part		
Great Skua	<i>Catharacta skua</i>	Cst_water		r	part		
Little Penguin	<i>Eudyptula minor</i>	Cst_water Cst_sand Isl (breed)		r	part		Low

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Sooty Oystercatcher	<i>Haematopus fuliginosus</i>	Cst_rock/sand (rare) Est		r	part		Medium
Pied Oystercatcher	<i>Haematopus longirostris</i>	Cst_sand/mud/rock		r	part		Medium
Pacific Gull	<i>Larus pacificus</i>	Cst		r	part		Low
Silver Gull	<i>Larus novaehollandiae</i>	Cst Fw_lot Isl		w	part		Low
Kelp Gull	<i>Larus dominicanus</i>	Cst_sand Isl		r	part		
Australasian Gannet	<i>Morus serrator</i>	Cst_water Isl (breed)		r	part		Medium
Wilson's Storm-Petrel	<i>Oceanites oceanites</i>	Cst_water		r	part	R	
Fairy Prion	<i>Pachyptila turtur</i>	Cst_water Is (breed)		r	part		Low
Common Diving-Petrel	<i>Pelecanoides urinatrix</i>	Cst_water Isl (breed)		r	part		Low
Black-faced Cormarant	<i>Phalacrocorax fuscescens</i>)	Cst_water/rock Est Isl		r	part		Medium
Mottled Petrel	<i>Pterodroma inexpectata</i>	Cst_water		r	part		
Great-Winged Petrel	<i>Pterodroma macroptera</i>	Cst_water		r	part		
Soft-Plumaged Petrel	<i>Pterodroma mollis</i>	Cst_water Isl (breed)		r	part	En	Medium
Fluttering Shearwater	<i>Puffinus gavia</i>	Cst_water		r	part		
Sooty Shearwater	<i>Puffinus griseus</i>	Cst_water Cst_sand Is (breed)		r	part		Low

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Hutton's Shearwater	<i>Puffinus huttoni</i>	Cst_water		r	part		
Short-Tailed Shearwater	<i>Puffinus tenuirostris</i>	Cst_water Cst_sand Isl		r	part		Low
Crested Tern	<i>Sterna bergii</i>	Cst_water Est Wet Fw_lot		r	part		Medium
Caspian Tern	<i>Sterna caspia</i>	Fw_lot/len Est		r	part		Medium
Fairy Tern	<i>Sterna nereis</i>	Cst_sand/mud Cst_water Est Wet Fw_lot		r	part	R	Medium
Shy Albatross	<i>Thalassarche cauta</i>	Cst_water Isl (breed)		r	part	V	Medium
Reptiles							
Lowland Copperhead	<i>Austrelaps superbus</i>	Sc_dry Bm Cst_hth		r	part		
Eastern Three-lined Skink	<i>Bassiana duperryi</i>	Sc_dry/sub.wod		r	part		
She-oak Skink	<i>Cyclodomorphus casuarinae</i>	Sc_dry Bm Cst_hth	e	w	part		

Common Name	Species	Habitats ²	Endemic ³	Distribution in TWWHA ⁴	Proportion of Tasmanian distribution in TWWHA ⁵	Listing ⁶	Risk
White-lipped Snake	<i>Drysdalia coronoides</i>	Al, Rf, Sc, Bm, Cst		w	part		
Northern Snow Skink	<i>Niveoscincus greeni</i>	Screes Al_hth Sc_sub.wod	e	r	prim		High
Metallic Skink	<i>Niveoscincus metallicus</i>	Al, Rf, Sc, Bm, Cst		w	part		
Southern Snow Skink	<i>Niveoscincus microlepidotus</i>	Screes Al_hth Sc_sub.wod	e	w	prim		High
Ocellated Skink	<i>Niveoscincus ocellatus</i>	Rocky habitats, sea level to subalpine	e	w	part		
Mountain Skink	<i>Niveoscincus oryocryptus</i>	Al_hth	e	r	ent		High
Pedra Branca Skink	<i>Niveoscincus palfreymani</i>	Isl (Pedra Branca)	e	r	ent	En	High
Tasmanian Tree Skink	<i>Niveoscincus pretiosus</i>	Sc_wet/dry/sub.wod Screes Cst_rock Isl	e	w	part		
Tiger Snake	<i>Notechis ater</i>	Al, Rf, Sc, Bm, Cst		w	part		
Southern Grass Skink	<i>Pseudemoia entrecasteauxii</i>	Sc_dry (grassy understorey) Cst_grs		r	part		
Blotched Bluetongue	<i>Tiliqua nigrolutea</i>	Sc_dry/sub.wod Cst_hth		r	part		

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Amphibians							
Moss Froglet	<i>Bryobatrachus nimbus</i>	Subalpine heathland Rf	e	r	ent		High
Brown Froglet	<i>Crinia signifera</i>	Alp_grs/sdg/hth Sc_wet/dry/sub.wod Bm Fw_lot Wet		w	part		Low
Tasmanian Froglet	<i>Crinia tasmaniensis</i>	Rf/mon Sc_wet/dry/sub.wod Bm Cst_hth Wet	e	w	part		Medium
Smooth Frog	<i>Geocrinia laevis</i>	Sc_dry/sub.wod Bm		r	part		
Eastern Banjo Frog	<i>Limnodynastes dumerili</i>	Wet Fw_lot		r	part		
Tasmanian Tree Frog	<i>Litoria burrowsae</i>	Rf Bm	e	w	prim		High
Brown Tree Frog	<i>Litoria ewingii</i>	Al, Rf, Sc, Bm, Cst Fw_lot Wet		w	part		Low

Common Name	Species	Habitats ²	Endemic ³	Distribution in TWWHA ⁴	Proportion of Tasmanian distribution in TWWHA ⁵	Listing ⁶	Risk
Fish: freshwater							
Short-Finned Eel	<i>Anguilla australis</i>	Fw_len		r	part		
Blackfish	<i>Gadopsis marmoratus</i>	Fw_len		r	part		
Climbing Galaxias	<i>Galaxias brevipinnis</i>	FW_len		w	part		
Tasmanian Mudfish	<i>Galaxias cleaveri</i>	Wet (coastal) Marine phase		r	part		
Clarence Galaxias	<i>Galaxias johnstoni</i>	Fw_lot/len Wet All central plateau	e	r	prim	En	High
Jollytail	<i>Galaxias maculatus</i>	Fw_lot/len (lowland/coastal) Marine phase		r	part		
Swamp Galaxias	<i>Galaxias parvus</i>	Wet Fw_len Bm	e	r	ent	R	High
Spotted Galaxias	<i>Galaxias truttaceus</i>	Fw_len Marine phase		w	part		
Lake Pedder Galaxias	<i>Galaxias pedderensis</i>	Fw_lot (translocation)	e	r	ent	En	Medium
Pouched Lamprey	<i>Geotria australis</i>	Fw_len Marine phase		r	part		
Tasmanian Whitebait	<i>Lovettia sealii</i>	Est (spawn) Marine phase		r	part		
Short-Headed Lamprey	<i>Mordacia mordax</i>	Fw_len Marine phase		r	part		
Western Paragalaxias	<i>Paragalaxius julianus</i>	Fw_lot All Central Plateau	e	r	ent	R	High

Common Name	Species	Habitats ²	Endemic ³	Distribution in TWWHA ⁴	Proportion of Tasmanian distribution in TWWHA ⁵	Listing ⁶	Risk
Australian Grayling	<i>Prototroctes maraena</i>	Fw_len Marine phase		r	part	V	Medium
Sandy	<i>Pseudophritus urvillii</i>	Fw_len		r	part		
Tasmanian Smelt	<i>Retropinna tasmanica</i>	Fw_len (lowland)		r	part		
Fish: estuarine							
Maugean Skate	<i>Dipturus sp</i>	Est (Bathurst Harbour and Macquarie harbour)	e		ent		Medium

¹ List of TWWHA vertebrate species and proportion of Tasmanian range in TWWHA from Driessen and Mallick (2003).

² See table below for list of TWWHA fauna habitats.

³ Endemic: e – endemic species; es – endemic sub-species.

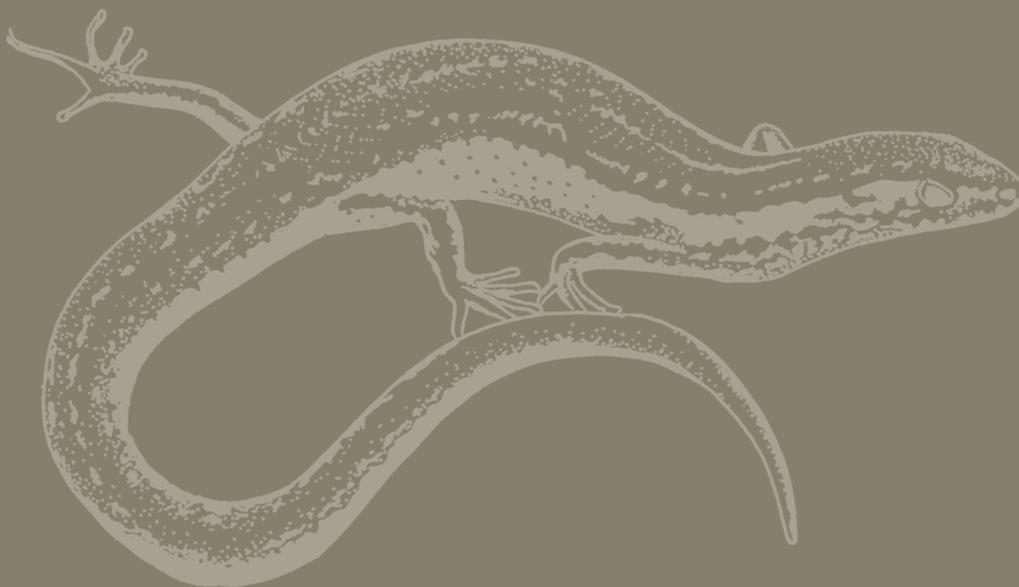
⁴ Distribution in WHA: r – restricted (<=5 records); w – widespread (> 5 records typically located in different parts of the WHA).

⁵ Proportion of Tas. distribution in WHA: ent – entire range within WHA; prim – majority of range within WHA (>75% of records); part – part of range within WHA (<=75%).

⁶ Listing on Tasmanian *Threatened Species Protection Act 1995*: R – rare; V – vulnerable; En – endangered.

List of habitat codes for TWWHA fauna habitats used in Appendix 1.

Habitat	Habitat code
Coastal habitats	Cst
Coastal heathland and scrub	Cst_hth
Coastal grasslands	Cst_grs
Coastal lagoons	Cst_lag
Coastal saltmarsh	Cst_salt
Beach and dune systems	Cst_sand
Rocky shorelines	Cst_rock
Mudflats	Cst_mud
Offshore islands	Isl
Coastal waters	Cst_water
Freshwater habitats	Fw
Wetlands	Fw_wet
Lakes	Fw_lot
Rivers and streams	Fw_len
Alpine habitats	Al
Alpine grasslands	Al_grs
Alpine heath: non-coniferous	Al_hth
Alpine heath and montane (coniferous) rainforest	Al_con_hth
Bolster heath	Al_bol
<i>Sphagnum</i> peatland	Al_sph
Rock screes	Al_scrie
Buttongrass moorland	Bm
Buttongrass moorland, heath and scrub mosaic	Bm_bm
Lowland rainforest	Rf
Sclerophyll forest communities	Sc
Wet eucalypt forest	Sc_wet
Dry forests	Sc_dry
Subalpine woodland	Sc_sub_wod
Caves	Cv
Estuarine	Est



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