2006). In the mediterranean-climate region of South Africa, climate change may have at least as significant an impact on endemic Protea species' extinction risk as land-use change does by 2020 (Bomhard et al., 2005). Based on all above findings and our compilation (Figure 4.4, Table 4.1) we estimate that on average 20% to 30% of species assessed are likely to be at increasingly high risk of extinction from climate change impacts possibly within this century as global mean temperatures exceed 2°C to 3°C relative to pre-industrial levels (this chapter). The uncertainties remain large, however, since for about 2°C temperature increase the percentage may be as low as 10% or for about 3°C as high as 40% and, depending on biota, the range is between 1% and 80% (Table 4.1; Thomas et al., 2004a; Malcolm et al., 2006). As global average temperature exceeds 4°C above pre-industrial levels, model projections suggest significant extinctions (40-70% species assessed) around the globe (Table 4.1).

Losses of biodiversity will probably lead to decreases in the provision of ecosystem goods and services with trade-offs between ecosystem services likely to intensify (National Research Council, 1999; Carpenter et al., 2005; Duraiappah et al., 2005). Gains in provisioning services (e.g., food supply, water use) are projected to occur, in part, at the expense of other regulating and supporting services including genetic resources, habitat provision, climate and runoff regulation. Projected changes may also increase the likelihood of ecological surprises that are detrimental for human well-being (Burkett et al., 2005; Duraiappah et al., 2005). Ecological surprises include rapid and abrupt changes in temperature and precipitation, leading to an increase in extreme events such as floods, fires and landslides, increases in eutrophication, invasion by alien species, or rapid and sudden increases in disease (Carpenter et al., 2005). This could also entail sudden shifts of ecosystems to less desired states (Scheffer et al., 2001; Folke et al., 2004; e.g., Chapin et al., 2004) through, for example, the exeedance of critical temperature thresholds, possibly resulting in the irreversible loss of ecosystem services, which were dependent on the previous state (Reid et al., 2005).

Table 4.1. *Projected impacts of climate change on ecosystems and population systems as reported in the literature for different levels of global mean annual temperature rise, ΔT_g, relative to pre-industrial climate – mean and range (event numbers as used in Figure 4.4 and Appendix 4.1). The global temperature change values are used as an indicator of the other associated climate changes that match particular amounts of ΔT_g, e.g., precipitation change and, where considered, change in the concentration of greenhouse gases in the atmosphere. Projections from the literature were harmonised into a common framework by down/upscaling (where necessary) from local to global temperature rise using multiple GCMs, and by using a common global mean temperature reference point for the year 1990 (after Warren, 2006). Whilst some of the literature relates impacts directly to global mean temperature rises or particular GCM scenarios, many studies give only local temperature rises, ΔT_{reg}, and hence require upscaling. The thirteen GCM output data sets used are taken from the IPCC DDC at http://www.ipcc-data.org/.*

No.[i]	ΔT_g above pre-ind [ii]	ΔT_g above pre-ind [iii] (range)	ΔT_{reg} above 1990 (range)	Impacts to unique or widespread ecosystems or population systems	Region	Ref. no.
1	0.6			Increased coral bleaching	Caribbean, Indian Ocean, Great Barrier Reef	2
2	0.6			Amphibian extinctions/extinction risks on mountains due to climate-change-induced disease outbreaks	Costa Rica, Spain, Australia	52, 54
3	<1.0			Marine ecosystems affected by continued reductions in krill possibly impacting Adelie penguin populations; Arctic ecosystems increasingly damaged	Antarctica, Arctic	42, 11, 14
4	1.3	1.1-1.6	1	8% loss freshwater fish habitat, 15% loss in Rocky Mountains, 9% loss of salmon	N. America	13
5	1.6	1.2-2.0	0.7-1.5	9-31% (mean 18%) of species committed to extinction	Globe [iv]	1
6	1.6			Bioclimatic envelopes eventually exceeded, leading to 10% transformation of global ecosystems; loss of 47% wooded tundra, 23% cool conifer forest, 21% scrubland, 15% grassland/steppe, 14% savanna, 13% tundra and 12% temperate deciduous forest. Ecosystems variously lose 2-47% areal extent.	Globe	6
7	1.6	1.1-2.1	1	Suitable climates for 25% of eucalypts exceeded	Australia	12
8	1.7	1-2.3	1°C SST	All coral reefs bleached	Great Barrier Reef, S.E. Asia, Caribbean	2
9	1.7	1.2-2.6		38-45% of the plants in the Cerrado committed to extinction	Brazil	1, 44
10	1.7	1.3-3		2-18% of the mammals, 2-8% of the birds and 1-11% of the butterflies committed to extinction	Mexico	1, 26
11	1.7	1.3-2.4	2	16% freshwater fish habitat loss, 28% loss in Rocky Mountains, 18% loss of salmon	N. America	13
12	<1.9	<1.6-2.4	<1	Range loss begins for golden bowerbird	Australia	4

i Same numbers as used in first column in Appendix 4.1.

ii The mean temperature change is taken directly from the literature, or is the central estimate of a range given in the literature, or is the mean of upscaling calculations (cf. caption).

iii The range of temperature change represents the uncertainty arising from the use of different GCM models to calculate global temperature change.

iv 20% of the Earth's land surface covered by study.

No.	ΔT_g above pre-ind	ΔT_g above pre-ind (range)	ΔT_{reg} above 1990 (range)	Impacts to unique or widespread ecosystems or population systems	Region	Ref. no.
13	1.9	1.6-2.4	1	7-14% of reptiles, 8-18% of frogs, 7-10% of birds and 10-15% of mammals committed to extinction as 47% of appropriate habitat in Queensland lost	Australia	1, 7
14	1.9	1.6-2.4	1	Range loss of 40-60% for golden bowerbird	Australia	4
15	1.9	1.0-2.8		Most areas experience 8-20% increase in number ≥7day periods with Forest Fire Weather Index >45: increased fire frequency converts forest and maquis to scrub, leads to more pest outbreaks	Mediterranean	34
16	2.1			41-51% loss in plant endemic species richness	S. Africa, Namibia	39
17	2.1	1.0-3.2	1-2	Alpine systems in Alps can tolerate local temperature rise of 1-2°C, tolerance likely to be negated by land-use change	Europe	8
18	2.1		1.4-2.6	13-23% of butterflies committed to extinction	Australia	1, 30
19	2.1	1.4-2.6		Bioclimatic envelopes of 2-10% plants exceeded, leading to endangerment or extinction; mean species turnover of 48% (spatial range 17-75%); mean species loss of 27% (spatial range 1- 68%)	Europe	22
20	2.2			3-16% of plants committed to extinction	Europe	1
21	2.2	2.1-2.3	1.6-1.8	15-37% (mean 24%) of species committed to extinction	Globe [iv]	1
22	2.2	1.7-3.2		8-12% of 277 medium/large mammals in 141 national parks critically endangered or extinct; 22-25% endangered	Africa	23
23	2.3	1.5-2.7	2°C SST	Loss of Antarctic bivalves and limpets	Southern Ocean	51
24	2.3	2.0-2.5		Fish populations decline, wetland ecosystems dry and disappear	Malawi, African Great Lakes	20
25	2.3	1.5-2.7	2.5-3.0	Extinctions (100% potential range loss) of 10% endemics; 51-65% loss of Fynbos; including 21-40% of Proteaceae committed to extinction; Succulent Karoo area reduced by 80%, threatening 2,800 plant species with extinction; 5 parks lose >40% of plant species	S. Africa	1, 5, 24, 25
26	2.3	2.3-4.0	2.5-3.0	24-59% of mammals, 28-40% of birds, 13-70% of butterflies, 18-80% of other invertebrates, 21-45% of reptiles committed to extinction; 66% of animal species potentially lost from Kruger National Park	S. Africa	1, 27
27	2.3	2.2-4.0		2-20% of mammals, 3-8% of birds and 3-15% of butterflies committed to extinction	Mexico	1, 26
28	2.3	1.6-3.2		48-57% of Cerrado plants committed to extinction	Brazil	1
29	2.3			Changes in ecosystem composition, 32% of plants move from 44% of area with potential extinction of endemics	Europe	16
30	2.3	1.6-3.2	3	24% loss freshwater fish habitat, 40% loss in Rocky Mountains, 27% loss of salmon.	N. America	13
31	2.4			63 of 165 rivers studied lose >10% of their fish species	Globe	19
32	2.4			Bioclimatic range of 25-57% (full dispersal) or 34-76% (no dispersal) of 5,197 plant species exceeded	Sub-Saharan Africa	3
33	>2.5			Sink service of terrestrial biosphere saturates and begins turning into a net carbon source	Globe	55, 56
34	2.5		2°C SST	Extinction of coral reef ecosystems (overgrown by algae)	Indian Ocean	9
35	2.5	1.9-4.3		42% of UK land area with bioclimate unlike any currently found there; in Hampshire, declines in curlew and hawfinch and gain in yellow-necked mouse numbers; loss of montane habitat in Scotland; potential bracken invasion of Snowdonia montane areas		57
36	2.5	2.0-3.0		Major loss of Amazon rainforest with large losses of biodiversity	S. America, Globe	21, 46
37	2.5			20-70% loss (mean 44%) of coastal bird habitat at 4 sites	USA	29
38	2.6	1.6-3.5		Most areas experience 20-34% increase in number ≥7day periods with Forest Fire Weather Index >45: increased fire frequency converts forest and maquis to scrub, causing more pest outbreaks	Mediterranean	34
39	2.6			4-21% of plants committed to extinction	Europe	1
40	2.7			Bioclimatic envelopes exceeded leading to eventual transformation of 16% of global ecosystems: loss of 58% wooded tundra, 31% cool conifer forest, 25% scrubland, 20% grassland/steppe, 21% tundra, 21% temperate deciduous forest, 19% savanna. Ecosystems variously lose 5-66% of their areal extent.	Globe	6

No.	ΔT_g above pre-ind	ΔT_g above pre-ind (range)	ΔT_{reg} above 1990 (range)	Impacts to unique or widespread ecosystems or population systems	Region	Ref. no.
41	2.8	1.2-4.5	1-3	Extensive loss/conversion of habitat in Kakadu wetland due to sea-level rise and saltwater intrusion	Australia	10
42	2.8	2.5-3.0		Multi-model mean 62% (range 40-100%) loss of Arctic summer ice extent, high risk of extinction of polar bears, walrus, seals; Arctic ecosystem stressed	Arctic	11,53
43	2.8	2.3-4.6	2.1-2.5	Cloud-forest regions lose hundreds of metres of elevational extent, potential extinctions ΔT_{reg} 2.1°C for C. America and ΔT_{reg} 2.5°C for Africa	C. America, Tropical Africa, Indonesia	17
44	2.8	2.1-3.1	3	Eventual loss of 9-62% of the mammal species from Great Basin montane areas	USA	32
45	2.8	1.9-3.8	3	38-54% loss of waterfowl habitat in Prairie Pothole region	USA	37, 38
46	2.9		3.2-6.6	50% loss existing tundra offset by only 5% eventual gain; millions of Arctic-nesting shorebird species variously lose up to 5-57% of breeding area; high-Arctic species most at risk; geese species variously lose 5-56% of breeding area	Arctic	14
47	2.9			Latitude of northern forest limits shifts N. by 0.5° latitude in W. Europe, 1.5° in Alaska, 2.5° in Chukotka and 4° in Greenland	Arctic	40
48	2.9	1.6-4.1		Threat of marine ecosystem disruption through loss of aragonitic pteropods	Southern Ocean	49
49	2.9	1.6-4.1		70% reduction in deep-sea cold-water aragonitic corals	Ocean basins	48
50	2.9		2.1-3.9	21-36% of butterflies committed to extinction; >50% range loss for 83% of 24 latitudinally-restricted species	Australia	1,30
51	2.9	2.6-3.3	2.1-2.8	21-52% (mean 35%) of species committed to extinction	Globe [iv]	1
52	2.9			Substantial loss of boreal forest	China	15
53	3.0			66 of 165 rivers studied lose >10% of their fish species	Globe	19
54	3.0	1.9-3.5		20% loss of coastal migratory bird habitat	Delaware, USA	36
55	3.1	2.3-3.7	2°C SST	Extinction of remaining coral reef ecosystems (overgrown by algae)	Globe	2
56	3.1	1.9-4.1	3-4	Alpine systems in Alps degraded	Europe	8
57	3.1	2.5-4.0	2	High risk of extinction of golden bowerbird as habitat reduced by 90%	Australia	4
58	3.1	1.8-4.2	3-4	Risk of extinction of alpine species	Europe	41
59	3.3	2.0-4.5		Reduced growth in warm-water aragonitic corals by 20%-60%; 5% decrease in global phytoplankton productivity	Globe	2, 47, 48
60	3.3	2.3-3.9	2.6-2.9	Substantial loss of alpine zone, and its associated flora and fauna (e.g., alpine sky lily and mountain pygmy possum)	Australia	45
61	3.3	2.8-3.8	2	Risk of extinction of Hawaiian honeycreepers as suitable habitat reduced by 62-89%	Hawaii	18
62	3.3		3.7	4-38% of birds committed to extinction	Europe	1
63	3.4			6-22% loss of coastal wetlands; large loss migratory bird habitat particularly in USA, Baltic and Mediterranean	Globe	35, 36
64	3.5	2.0-5.5		Predicted extinction of 15-40% endemic species in global biodiversity hotspots (case “narrow biome specificity”)	Globe	50
65	3.5	2.3-4.1	2.5 – 3.5	Loss of temperate forest wintering habitat of monarch butterfly	Mexico	28
66	3.6	2.6-4.3	3	Bioclimatic limits of 50% of eucalypts exceeded	Australia	12
67	3.6	2.6-3.7		30-40% of 277 mammals in 141 parks critically endangered/extinct; 15-20% endangered	Africa	23
68	3.6	3.0-3.9		Parts of the USA lose 30-57% neotropical migratory bird species richness	USA	43
69	3.7			Few ecosystems can adapt	Globe	6
70	3.7			50% all nature reserves cannot fulfil conservation objectives	Globe	6
71	3.7			Bioclimatic envelopes exceeded leading to eventual transformation of 22% of global ecosystems; loss of 68% wooded tundra, 44% cool conifer forest, 34% scrubland, 28% grassland/steppe, 27% savanna, 38% tundra and 26% temperate deciduous forest. Ecosystems variously lose 7-74% areal extent.	Globe	6
72	3.9			4-24% plants critically endangered/extinct; mean species turnover of 63% (spatial range 22-90%); mean species loss of 42% (spatial range 2.5-86%)	Europe	22

No.	ΔT_g above pre-ind	ΔT_g above pre-ind (range)	ΔT_{reg} above 1990 (range)	Impacts to unique or widespread ecosystems or population systems	Region	Ref. no.
73	4.0	3.0-5.1	3	Likely extinctions of 200-300 species (32-63%) of alpine flora	New Zealand	33
74	>4.0		3.5	38-67% of frogs, 48-80% of mammals, 43-64% of reptiles and 49-72% of birds committed to extinction in Queensland as 85-90% of suitable habitat lost	Australia	1, 7
75	>>4.0		5	Bioclimatic limits of 73% of eucalypts exceeded	Australia	12
76	>>4.0		5	57 endemic frogs/mammal species eventually extinct, 8 endangered	Australia	7
77	>>4.0		7	Eventual total extinction of all endemic species of Queensland rainforest	Australia	7
78	5.2			62-100% loss of bird habitat at 4 major coastal sites	USA	29

Sources by Ref. no.: 1-Thomas et al., 2004a; 2-Hoegh-Guldberg, 1999; 3-McClean et al., 2005; 4-Hilbert et al., 2004; 5-Rutherford et al., 2000; 6-Leemans and Eickhout, 2004; 7-Williams et al., 2003; 8-Theurillat and Guisan, 2001; 9-Sheppard, 2003; 10-Eliot et al., 1999; 11-Symon et al., 2005; 12-Hughes et al., 1996; 13-Preston, 2006; 14-Zöckler and Lysenko, 2000; 15-Ni, 2001; 16-Bakkenes et al., 2002; 17-Still et al., 1999; 18-Benning et al., 2002; 19-Xenopoulos et al., 2005; 20-ECF, 2004; 21-Cox et al., 2004; 22-Thuiller et al., 2005b; 23-Thuiller et al., 2006b; 24-Midgley et al., 2002; 25-Hannah et al., 2002a; 26-Peterson et al., 2002; 27-Erasmus et al., 2002; 28-Villers-Ruiz and Trejo-Vazquez, 1998; 29-Galbraith et al., 2002; 30-Beaumont and Hughes, 2002; 31-Kerr and Packer, 1998; 32-McDonald and Brown, 1992; 33-Halloy and Mark, 2003; 34-Moriondo et al., 2006; 35-Nicholls et al., 1999; 36-Najjar et al., 2000; 37-Sorenson et al., 1998; 38-Johnson et al., 2005; 39-Broennimann et al., 2006; 40-Kaplan et al., 2003; 41-Theurillat et al., 1998; 42-Forcada et al., 2006; 43-Price and Root, 2005; 44-Siqueira and Peterson, 2003; 45-Pickering et al., 2004; 46-Scholze et al., 2006; 47-Raven et al., 2005; 48-Cox et al., 2000; 49-Orr et al., 2005; 50-Malcolm et al., 2006; 51-Peck et al., 2004; 52-Pounds et al., 2006; 53-Arzel et al., 2006; 54-Bosch et al., 2006; 55-Lucht et al., 2006; 56-Schaphoff et al., 2006; 57-Berry et al., 2005.

There is detailed information on the derivation for each entry in Table 4.1 listed in Appendix 4.1.

4.5 Costs and valuation of ecosystem goods and services

There is growing interest in developing techniques for environmental accounting. To that end, definitions of ecosystem goods and services are currently fluid. For example, ecosystem services accrue to society in return for investing in or conserving natural capital (Heal, 2007), or ecosystem services are ultimately the end products of nature, the aspects of nature that people make choices about (Boyd, 2006). Definitions aside, all humans clearly rely on ecosystem services (Reid et al., 2005). While many efforts have been made to use standard economic techniques to estimate the economic value of ecosystem goods and services (Costanza et al., 1997, 2000; Costanza, 2000, 2001; Daily et al., 2000; Giles, 2005; Reid et al., 2005), others argue that such efforts are not only largely futile and flawed (Pearce, 1998; Toman, 1998b; Bockstael et al., 2000; Pagiola et al., 2004), but may actually provide society a disservice (Ludwig, 2000; Kremen, 2005). The estimates from these techniques range from unknown (incomparability cf. Chang, 1997), or invaluable, or infinite (Toman, 1998b) because of lack of human substitutes, to about 38×10^{12} US$ *per annum* (updated to 2000 levels – Costanza et al., 1997; Balmford et al., 2002; Hassan et al., 2005), which is larger but of similar magnitude than the global gross national product (GNP) of 31×10^{12} US$ *per annum* (2000 levels). These monetary estimates are usually targeted at policy-makers to assist assessments of the economic benefits of the natural environment (Farber et al., 2006) in response to cost-benefit paradigms. Some argue (Balmford et al., 2002, 2005; Reid et al., 2005) that unless ecosystem values are recognised in economic terms, ecosystems will continue their decline, placing the planet's ecological health at stake (Millennium Ecosystem Assessment, 2005). Others argue that ecosystems provide goods and services which are invaluable and need to be conserved on more fundamental principles, i.e., the precautionary principle of not jeopardising the conditions for a decent, healthy and secure human existence on this planet (e.g., Costanza et al., 2000; van den Bergh, 2004), or a moral and ethical responsibility to natural systems not to destroy them.

What is sometimes lost in the arguments is that natural capital (including ecosystem goods and services) is part of society's capital assets (Arrow et al., 2004). The question then may be considered as whether one should maximise present value or try to achieve a measure of sustainability. In either case, it is the change in quantities of the capital stock that must be considered (including ecosystem services). One approach in considering valuation of ecosystem services is to calculate how much of one type of capital asset would be needed to compensate for the loss of one unit of another type of capital asset (Arrow et al., 2004). What is not disputed is that factoring in the full value of ecosystem goods and services, whether in monetary or non-monetary terms, distorts measures of economic wealth such that a country may be judged to be growing in wealth according to conventional indicators, while it actually becomes poorer due to the loss of natural resources (Balmford et al., 2002; Millennium Ecosystem Assessment, 2005; Mock, 2005 p. 33-53.). Ignoring such aspects almost guarantees opportunity costs. For instance Balmford et al. (2002) estimated a benefit-cost ratio of at least 100:1 for an effective global conservation programme setting aside 15% of the current Earth's surface if all aspects conventionally ignored are