The Growing Burden of Invasive Melanoma: Projections of Incidence Rates and Numbers of New Cases in Six Susceptible Populations through 2031

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New melanoma therapies are being developed rapidly, complementing prevention and detection strategies for disease control. Estimating the future burden of melanoma is necessary for deciding how best to deploy limited resources to achieve effective melanoma control. Using three decades of cancer registry data (1982–2011) from six populations with moderate to high melanoma incidence (US whites and the populations of the United Kingdom, Sweden, Norway, Australia, New Zealand), we applied age-period-cohort models to describe current trends and project future incidence rates and numbers of melanomas out to 2031. Between 1982 and 2011, melanoma rates in US whites, and the populations of the United Kingdom, Sweden, and Norway increased at more than 3% annually and are projected to continue rising until at least 2022. Melanoma incidence in Australia has been declining since 2005 (−0.7% per year), and melanoma incidence in New Zealand is increasing but is projected to decline soon. The numbers of new melanoma cases will rise in all six populations because of aging populations and high age-specific rates in the elderly. In US whites, annual new cases will rise from around 70,000 in 2007–2011 to 116,000 in 2026–2031, with 79% of the increase attributable to rising age-specific rates and 21% to population growth and aging. The continued increases in case numbers in all six populations through 2031 will increase the challenges of melanoma control.

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INTRODUCTION

Cutaneous melanoma, cancer of the skin's pigment cells, is caused by ultraviolet UV radiation from natural (sunlight) or artificial (tanning beds) sources (IARC Working Group on the Evaluation of Carcinogenic Risks to Humans, 2012). In susceptible, fair-skinned populations around the world, melanoma incidence has been rising steadily during recent decades (Erdmann et al., 2013). In response to these rising rates and the known causal role of excessive UV exposure, health agencies in many regions have launched campaigns that aim to reduce hazardous sun exposure and thereby lower melanoma incidence. However, the history of and approaches to prevention campaigns have differed across populations.

In the United States, for example, multiple agencies have promoted sun protection, albeit in an uncoordinated fashion (Lazovich et al., 2012). The US Surgeon General recently published a *Call to Action to Prevent Skin Cancer* to promote sun protection policies and reduce harms from indoor tanning (US Department of Health and Human Services, 2014). In the United Kingdom (UK), national primary prevention efforts commenced in the 1990s, and the SunSmart Campaign followed in 2003. Since then, other UK organizations have launched campaigns targeted at particular audiences. In Norway and Sweden, the respective national cancer societies and radiation safety agencies have delivered primary prevention messages since the 1990s, albeit with limited resources and a variety of approaches (Nilsen et al., 2011; Nilsen et al., 2008). The high-incidence populations of Australia and New Zealand have been exposed to mass-media campaigns since the early 1980s (Iannacone and Green, 2014; Watts et al., 2002).

Given the maturity of prevention campaigns and their apparent success in changing behavior, particularly in Australia and New Zealand (Buller et al., 2011; Centers for Disease Control and Prevention, 2012; Makin et al., 2013), one might reasonably expect to see a downturn in melanoma incidence and numbers of new cases. Indeed, there have been recent reports of declining rates within younger birth cohorts in some countries (Iannacone et al., 2015; Weir et al., 2011), although as yet these trends at early ages have not had a discernible impact on total melanoma incidence (Erdmann et al., 2013). Recently, targeted therapies for melanoma have been approved in a number of jurisdictions, with an as yet uncertain impact on health expenditures into the future. To study these issues, we analyzed recent trends and estimated

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Abbreviations: APC, average annual percentage rate change; UK, United Kingdom

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future melanoma incidence in six populations of mainly European heritage with markedly different patterns of UV exposure and varying approaches to melanoma control: US whites and the populations of the UK, Sweden, Norway, Australia, and New Zealand.

RESULTS

Population trends in age-standardized invasive melanoma incidence and mortality

In all six populations, age-standardized invasive melanoma incidence was substantially higher in 2011 than 1982 (ranging from 2-fold higher in Australia to 4-fold higher in the UK), although the trajectories through which melanoma rates increased varied across populations (Figure 1). In US whites, age-standardized invasive melanoma incidence increased at around 3.3% per year between 1982 and 2006, with slower increases in incidence thereafter (Figure 1a). UK rates increased rapidly during the 1980s, stabilized briefly, and then increased continuously at more than 4% per year since 1991 (Figure 1b). Melanoma rates in both Sweden and Norway climbed from around 10−12 $\times$ 10^{-5} person-years in the early 1980s to around 20 $\times$ 10^{-5} person-years by the early 2000s and then increased rapidly since 2004 (Sweden average annual percentage rate change [APC] = 6.11, Norway APC = 5.09) (Figure 1c and d). In contrast to continuing increases observed in northern hemisphere populations, melanoma incidence in Australia transitioned through three distinct phases during the observation period, characterized as rapid growth (1982−1987, APC = 6.91), modest growth (1987−2005, APC = 1.68) and recent decline (2005−2011, APC = −0.68) (Figure 1e). The situation in New Zealand was complicated by changes in cancer registration practices in 1994, but there were steady increases before the change (1982−1993, APC = 2.75), followed by slow but statistically significant increases in melanoma incidence (1997−2011, APC = 1.16) (Figure 1f).

Projection algorithms suggest that age-standardized invasive melanoma incidence in US whites will peak at around 32 $\times$ 10^{-5} person-years by 2022−2026, whereas rates in the three northern European countries are anticipated to stabilize somewhat later (Table 1). In contrast, melanoma rates in Australia peaked around 2005 (Figure 1) and are projected to continue declining. New Zealand appears to be following a similar trajectory to Australia but about a decade later, with age-standardized incidence anticipated to peak at about 51 $\times$ 10^{-5} person-years in 2012−2016 and then to decline slowly thereafter.

Age-standardized melanoma mortality has also been rising in all six countries during the past three decades, albeit less rapidly than incidence and with different rates of increase across countries. The highest age-standardized melanoma mortality rates were observed in New Zealand and Australia, with average annual increases in rates of around 1.5% during the past decade (Figure 2e and f). Of the northern hemisphere nations, Norway and Sweden now have the highest melanoma mortality rates (approaching 6 $\times$ 10^{-5} person-years in Norway and 4 $\times$ 10^{-5} person-years in Sweden) and have undergone continuous, steady rises in mortality for decades (APC = 1.51−1.81) (Figure 2c and d). Melanoma mortality rates in US whites and the UK population are slightly lower, and although rates continue to rise steadily in the UK (APC = 1.59), US mortality rates are climbing much more slowly (APC = 0.20) (Figure 2a and b).

Population trends in age-specific invasive melanoma incidence

In all six populations, the highest age-specific invasive melanoma rates were observed in the elderly (>80 years), and these are projected to continue rising for the foreseeable future (Figure 3, see Supplementary Table S1 online). Differences in melanoma trends across populations were evident in young (20−39 years) and middle-aged (40−59 years) adults. Whereas in Australia and New Zealand, age-specific melanoma incidence for those younger than 60 years peaked around 2002−2006 and then declined (Figure 3e and f), melanoma rates among those younger than 60 years are not projected to stabilize until 2021 in US whites (Figure 3a) and until 2026 in the UK, Sweden, and Norway (Figure 3b−d).

Numbers of persons diagnosed with and dying from invasive melanoma

The numbers of persons with invasive melanoma increased in each population from 1982 to 2011, with relative increases in new melanoma cases ranging from 133% in Norway to 278% in the UK (Table 2). Numbers of deaths from melanoma in each country during the past three decades are reported in Supplementary Table S2 online. Most of the increase in new melanoma diagnoses was attributable to changes in age-specific melanoma incidence, most evident in the UK and Sweden. During the forecast period (2012−2031), all six populations can expect large increases in the numbers of invasive melanomas diagnosed. The number of invasive melanomas diagnosed in US whites will rise from about 70,000 per year in 2007−2011 to more than 116,000 per year in 2026−2031. Over the entire interval of 1982−2031, the number of US whites diagnosed with melanoma each year will quadruple, of which 79% of the excess can be attributed to increases in the age-specific rates of melanoma and 21% can be attributed to population growth and aging. Changes of approximately similar magnitude were projected for the other populations. Relative to 1982, the excess numbers of persons with melanoma in 2031 will rise substantially in the UK (585%), Sweden (388%), Norway (333%), Australia (291%), and New Zealand (362%). In all populations except Australia, most of the increase in numbers of persons diagnosed with melanoma will be attributable to increases in age-specific melanoma rates rather than population growth.

Observed versus expected cases, assuming historical melanoma rates prevailed

Finally, we sought to compare the number of invasive melanomas that were recorded in each population in 2002−2006 and 2007−2011 with the number that would have occurred in those time periods assuming that underlying melanoma incidence rates had continued on the trajectories prevailing during the 20 years prior (Table 3). Under those assumptions, the numbers of melanomas observed in 2007−2011 were higher than expected in the United States (+5%), the UK (+19%), Sweden (+27%), and Norway (+14%). The magnitudes of the differences were

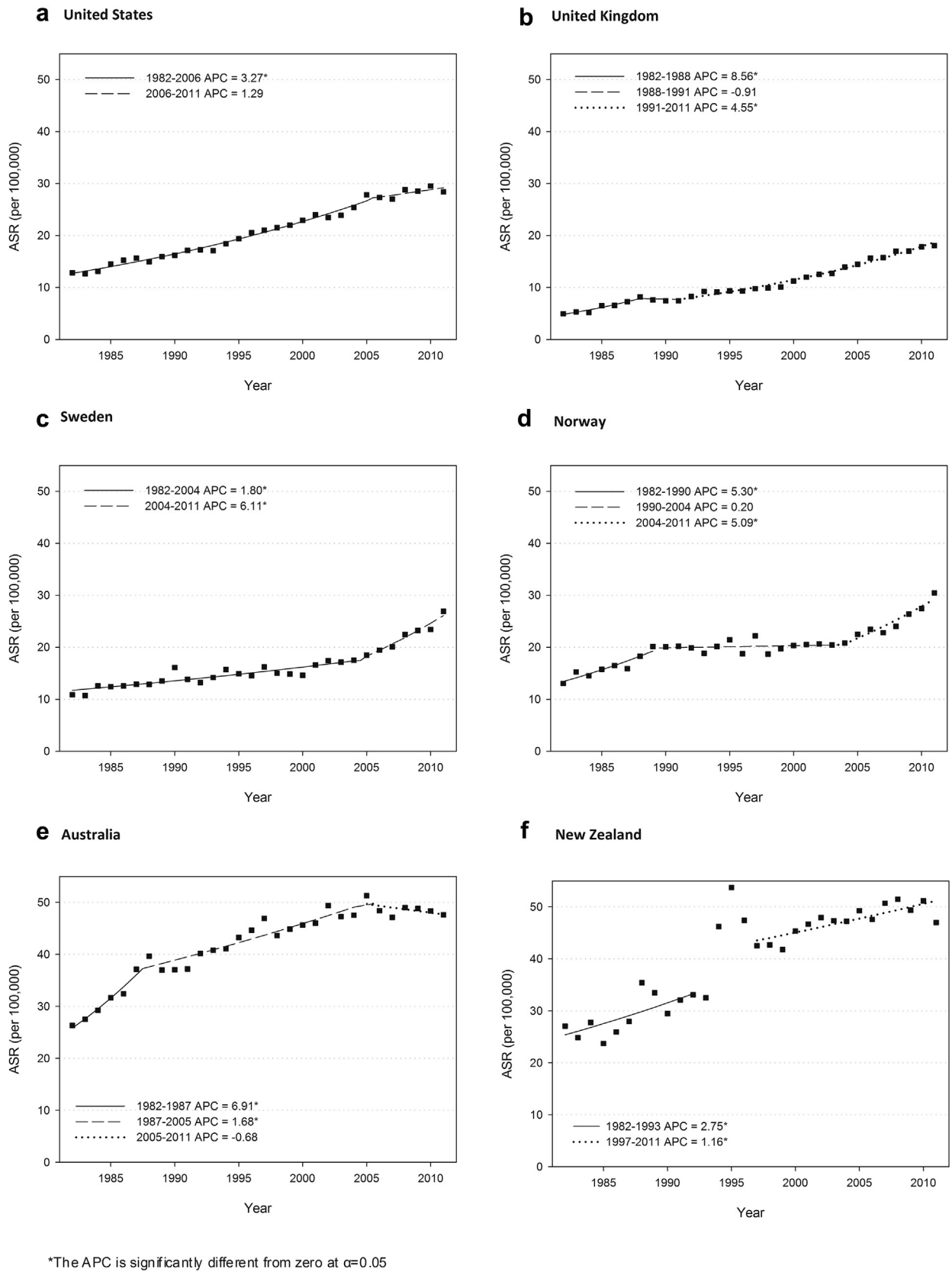

Figure 1. Age-standardized melanoma incidence (US 2000 population) from 1982–2011 and annual percentage change in six populations. **(a)** US whites. **(b)** United Kingdom. **(c)** Sweden. **(d)** Norway. **(e)** Australia. **(f)** New Zealand. APC, annual percentage change; ASR, age standardized rate (US 2000).

Table 1. Observed and projected melanoma incidence for six populations in 5-year time periods (crude and standardized to world and US populations)[1]

	Observed Data						Projected Data			
	1982–1986	1987–1991	1992–1996	1997–2001	2002–2006	2007–2011	2012–2016	2017–2021	2022–2026	2027–2031
USA whites										
Crude rate	12.8	15.5	18.3	22.5	26.7	31.0	36.1	39.9	42.5	43.7
US ASR	13.7	16.0	18.6	22.3	25.6	28.5	30.9	32.3	32.4	31.5
United Kingdom										
Crude rate	5.8	7.9	9.7	11.7	15.6	19.8	24.6	28.6	31.4	32.5
US ASR	5.7	7.6	9.1	10.6	13.9	17.1	20.6	23.2	24.5	24.4
Sweden										
Crude rate	13.0	15.5	16.3	18.1	21.7	28.3	36.0	42.5	47.1	49.0
US ASR	11.8	13.7	14.3	15.4	17.9	23.1	29.0	33.5	35.8	35.8
Norway										
Crude rate	15.0	19.2	20.8	21.9	23.9	29.9	35.8	41.0	44.3	45.6
US ASR	14.9	18.8	19.7	20.2	21.6	26.3	31.3	34.7	36.0	35.5
Australia										
Crude rate	26.4	34.6	39.9	45.1	50.6	51.6	52.1	52.1	52.0	52.1
US ASR	29.5	37.6	42.1	45.4	48.8	48.2	46.9	45.3	43.3	41.2
New Zealand										
Crude rate	22.1	28.2	39.3	41.4	47.3	51.8	56.0	59.6	62.3	63.8
US ASR	25.9	31.7	42.8	43.9	47.9	49.9	50.8	50.3	48.5	45.5

Abbreviation: ASR, age standardized rate (US 2000).
[1]All rates are expressed as number per 100,000 person-years.

systematically greater for 2007–2011 than 2002–2006, reflecting the effects of steadily increasing incidence in these countries during recent time periods. In contrast, the numbers of new melanoma cases in Australia and New Zealand were 6–10% lower in 2007–2011 than would have been expected had the trends in melanoma incidence continued on their earlier course.

DISCUSSION

Agencies tasked with developing cancer control strategies—such as the US Surgeon General (US Department of Health and Human Services, 2014), the UK National Health Service (Independent Cancer Taskforce, 2015), and the Cancer Institute NSW in Australia (Cancer Institute NSW, 2012)—use estimates of future melanoma incidence on which to develop their policies and advice. In an era during which new therapies for melanoma are being developed rapidly (Michielin and Hoeller, 2015), consideration of the likely future burden is necessary to decide how best to deploy limited resources toward effective disease control. For US whites and populations of the UK, Sweden, and Norway, invasive melanoma incidence is projected to rise until 2022–2026 and then possibly stabilize. Melanoma incidence in Australia and New Zealand is projected to decline in the years ahead. However, for all populations studied, and particularly in New Zealand, no declines in crude melanoma rates are anticipated for the foreseeable future, because of the exceptionally high rates of melanoma in the elderly and their increasing representation in those populations over time. This means that there will be large increases in the absolute numbers of new melanomas diagnosed in each population in the next two decades. These increases will be most notable in the UK, where the numbers of melanomas diagnosed each year in 2027–2031 will be more than 6-fold higher than in 1982–1986, mostly because of substantially higher risks of melanoma among UK residents than during earlier time periods. It remains unclear how new therapies will be deployed in the future, but based on the predictions for numbers of new cases presented here and assuming that 10–20% of melanoma patients progress to late-stage disease, then in the United States alone up to 24,000 melanoma patients each year theoretically could be candidates for new therapies by 2031.

We assessed melanoma burden using measures of incidence and mortality. Other measures, such as disability-adjusted life years, have also been used to assess melanoma burden. We did not estimate melanoma burden using such measures because the calculations require estimates of utility weights and distributions of melanoma disease states that are not available for all jurisdictions for all time periods, and would require assessments beyond the scope of the present article.

Projections of future melanoma incidence for the US population were reported recently by the Centers for Disease Control (Guy Jr et al., 2015). Our report extends those findings by estimating future melanoma incidence for five other countries and estimating rates of change in melanoma incidence. In addition, we estimated the respective contributions of population structure and risk to future melanoma burden. We did not attempt to project melanoma mortality into the future, however, because survival is likely to change markedly with the advent of new therapies for advanced (fatal) melanoma. Erdmann et al. (2013) conducted age-period-cohort modeling for eight populations (which overlapped with five populations analyzed in our report: US whites and the populations of the UK, Norway, Australia, and New

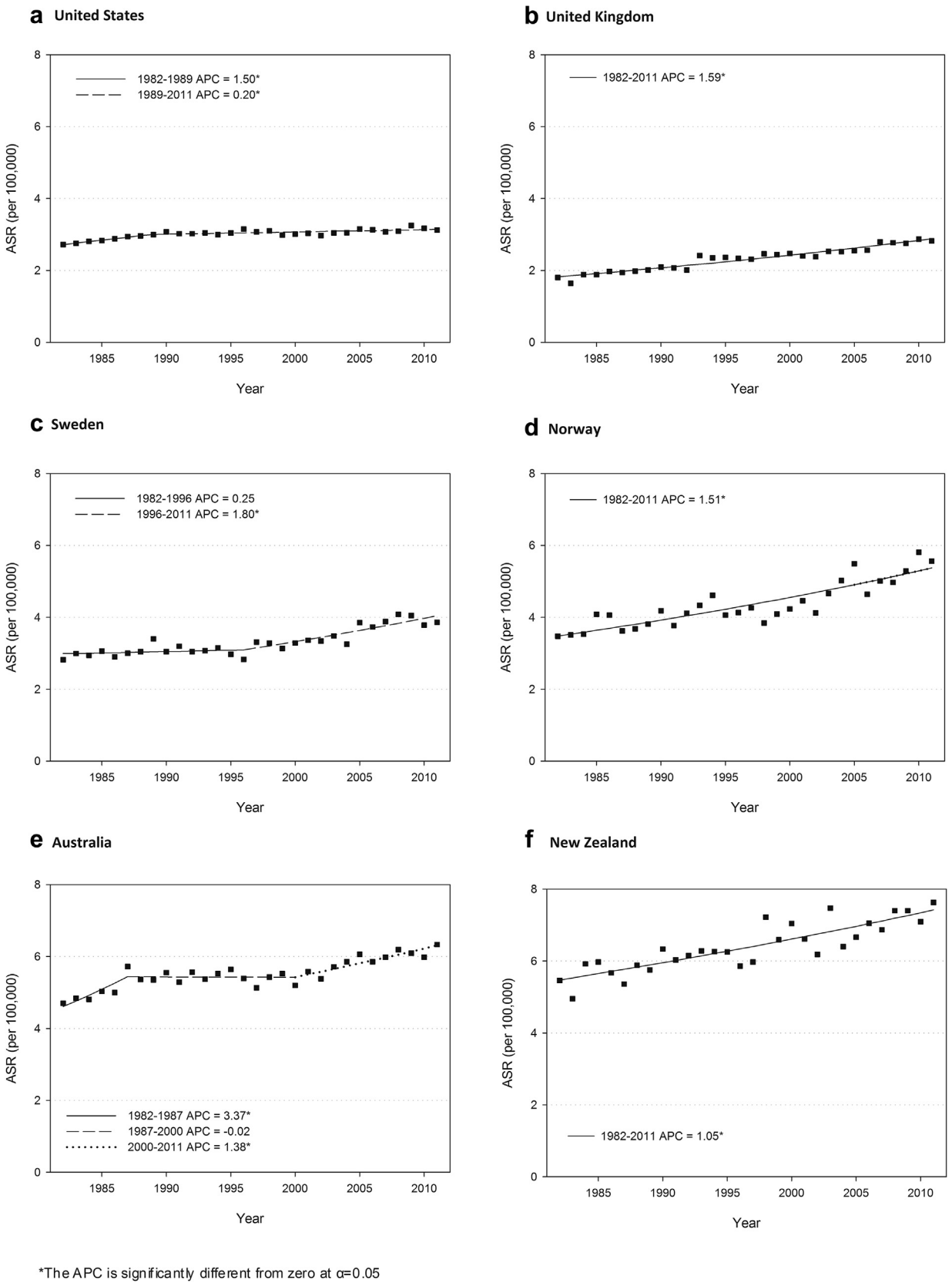

Figure 2. Age-standardized melanoma mortality (US 2000 population) from 1982–2011 and annual percentage change in six populations. **(a)** US whites. **(b)** United Kingdom. **(c)** Sweden. **(d)** Norway. **(e)** Australia. **(f)** New Zealand. APC, annual percentage change; ASR, age standardized rate (US 2000).

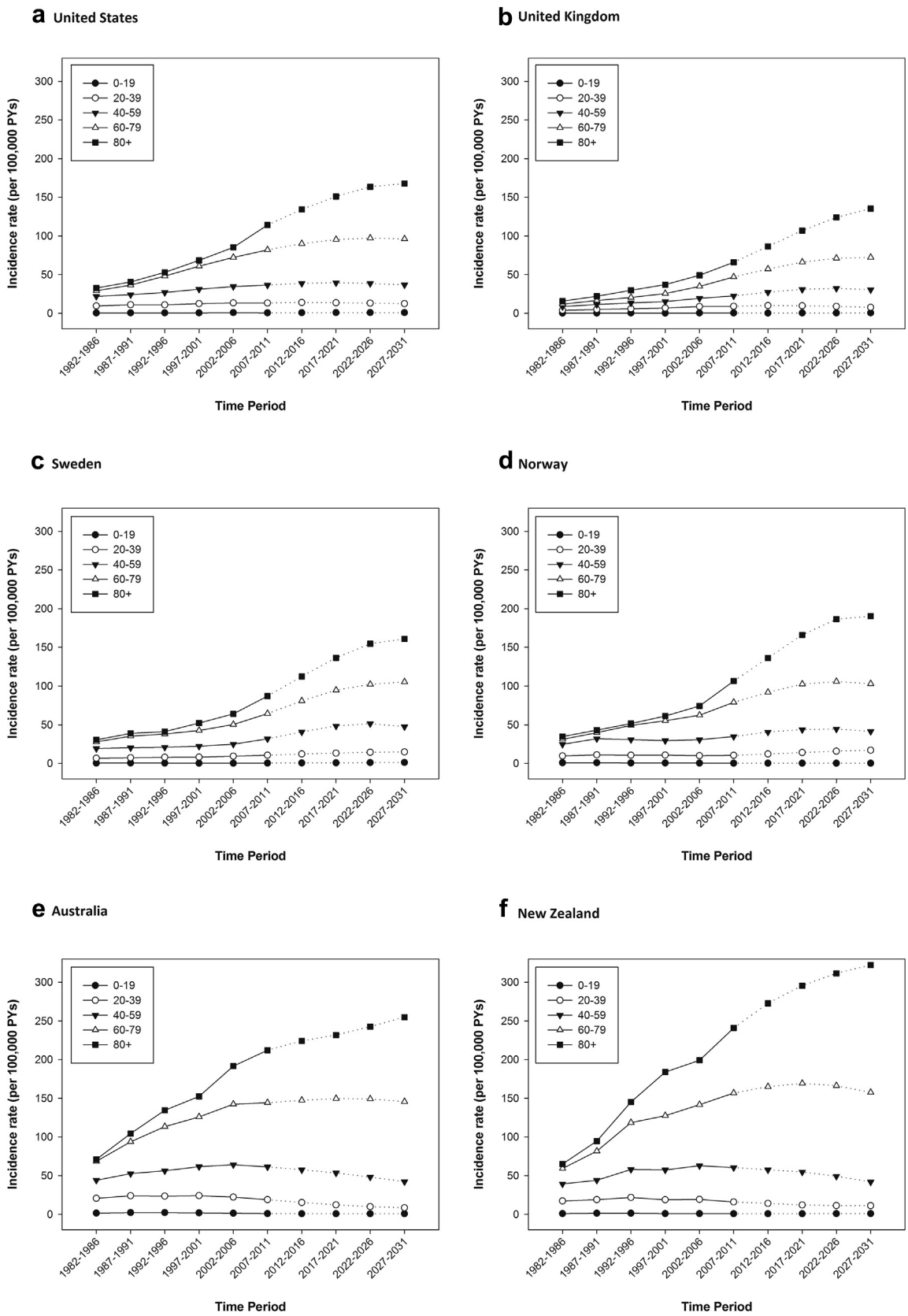

Figure 3. Age-specific incidence of melanoma (in 20-year age groups) in six populations: observed (1982–2011) and projected (2012–2031). **(a)** US whites. **(b)** United Kingdom. **(c)** Sweden. **(d)** Norway. **(e)** Australia. **(f)** New Zealand. PYs, patient-years.

Table 2. Observed and projected numbers of annual melanoma diagnoses for six populations in 5-year time periods with proportions attributable to changes in risk and population structure

	Observed Data						Projected Data			
	1982–1986	1987–1991	1992–1996	1997–2001	2002–2006	2007–2011	2012–2016	2017–2021	2022–2026	2027–2031
US whites—SEER melanomas,[1] n	2,338	2,911	3,617	4,608	5,556	6,597	8,443	9,535	10,413	10,946
Estimated total, N	24,872	30,969	38,478	49,022	59,100	70,179	89,814	101,432	110,775	116,448
Excess melanomas from baseline, %	—	25	55	97	138	182	261	308	345	368
Population growth from baseline, %	—	3	8	12	14	17	28	31	34	37
Excess melanomas, % due to risk[2]	—	73	73	78	81	81	80	80	80	79
Excess melanomas, % due to population change[3]	—	27	27	22	19	19	20	20	20	21
United Kingdom—total melanomas, N	3,275	4,519	5,636	6,849	9,386	12,364	15,857	18,957	21,242	22,427
Excess melanomas from baseline, %	—	38	72	109	187	278	384	479	549	585
Population growth from baseline, %	—	1	3	4	6	10	14	17	20	22
Excess melanomas, % due to risk	—	92	91	91	92	93	93	93	93	93
Excess melanomas, % due to population change	—	8	9	9	8	7	7	7	7	7
Sweden—total melanomas, N	1,081	1,316	1,431	1,605	1,944	2,631	3,513	4,341	4,955	5,270
Excess melanomas from baseline, %	—	22	32	49	80	143	225	302	359	388
Population growth from baseline, %	—	2	5	6	8	11	17	22	26	29
Excess melanomas, % due to risk	—	85	79	79	82	86	88	89	89	89
Excess melanomas, % due to population change	—	15	21	21	18	14	12	11	11	11
Norway—total melanomas, N	619	810	900	976	1,097	1,443	1,828	2,206	2,502	2,683
Excess melanomas from baseline, %	—	31	45	58	77	133	195	256	304	333
Population growth from baseline, %	—	2	5	8	11	17	23	30	36	42
Excess melanomas, % due to risk	—	87	82	77	76	80	82	83	82	81
Excess melanomas, % due to population change	—	13	18	23	24	20	18	17	18	19
Australia—total melanomas, N	4,112	5,805	7,108	8,486	10,095	11,162	12,283	13,465	14,736	16,075
Excess melanomas from baseline, %	—	41	73	106	146	171	199	227	258	291
Population growth from baseline, %	—	8	14	21	28	39	51	66	82	98
Excess melanomas, % due to risk	—	72	69	67	67	63	59	55	52	49
Excess melanomas, % due to population change	—	28	31	33	33	37	41	45	48	51
New Zealand—total melanomas, N	718	945	1,380	1,581	1,921	2,237	2,540	2,847	3,110	3,313
Excess melanomas from baseline, %	—	32	92	120	168	212	254	297	333	362
Population growth from baseline, %	—	3	8	18	25	33	40	47	54	60
Excess melanomas, % due to risk	—	76	82	74	73	72	71	70	69	67
Excess melanomas, % due to population change	—	24	18	26	27	28	29	30	31	33

Abbreviations: SEER, Surveillance, Epidemiology, and End Results program.

[1]SEER registries cover 9.4% of the US population. The proportion has been stable over the observation period and is expected to remain so over the projection period.

[2]The difference in the number of melanomas between baseline and future time period attributable to changes in age-specific rates.

[3]The difference in the number of melanomas between baseline and future time period attributable to changes in population size and age structure.

Zealand). They reported historical trends of steady increases in overall melanoma incidence in most fair-skinned populations around the world but noted recent stabilizations in Australia, New Zealand and US whites, with possible declines in incidence among those aged 25–44 years in Australia, New Zealand, US whites, and Norway; they concluded that the declines were more likely explained by birth cohort than calendar period. Similarly, Autier et al. (2015) examined historical trends in melanoma mortality in various regions around the world and concluded that although numbers of deaths from melanoma would continue to rise in the next several decades, age-standardized mortality rates would likely decrease into the future as more recent birth cohorts progressively age. Although these observations broadly parallel ours, there are some important differences. In particular, Erdmann et al. (2013) and Autier et al. (2015) standardized incidence rates to the 1960 world standard population (Boschi-Pinto et al., 2001), which gives disproportionately greater weight to young age groups and less weight to older age groups than the US 2000 standard population (Anderson and Rosenberg, 1998). This serves to dampen the effects of rising incidence in the elderly and inflate the effects of falling incidence in the young. Our use of the more appropriately weighted US 2000 reference

Table 3. Observed new melanoma cases for 2002–2006 and 2007–2011 in six populations compared with predicted new melanoma cases based on incidence projections from 1982–2001

	2002–2006	2007–2011
US whites		
Observed, n	59,100	70,179
Predicted, n	58,264	66,743
% Difference	+1	+5
United Kingdom		
Observed, n	9,386	12,364
Predicted, n	8,467	9,984
% Difference	+10	+19
Norway		
Observed, n	1,097	1,443
Predicted, n	1,108	1,238
% Difference	−1	+14
Sweden		
Observed, n	1,944	2,631
Predicted, n	1,786	1,930
% Difference	+8	+27
Australia		
Observed, n	10,095	11,162
Predicted, n	10,399	12,269
% Difference	−3	−10
NZ		
Observed	1,921	2,237
Predicted	1,984	2,373
% Difference	−3	−6

population suggests that although rates in Australia are now declining and appear on the cusp of doing so in New Zealand, overall melanoma incidence in US whites and European populations is likely to increase for another decade or so.

The recent declines in overall age-standardized melanoma incidence observed in Australia are highly significant and complement earlier reports suggesting declining rates in the young (Iannacone et al., 2015). Although some have argued that such declines may be an artefact caused by rising numbers of young migrants at low risk of melanoma (Czarnecki, 2014), a detailed analysis has shown that the magnitude of population dilution is too small to explain the observed downturn in rates among the young (Baade et al., 2015). It is possible that the declining melanoma rates among the young are due to lower levels of sun exposure than in earlier generations (Lucas et al., 2013). There is some evidence to support this proposition, although surveys of Australian youth in recent decades have shown only modest improvements in attitudes and behaviors regarding tanning, sunburns, or use of protective clothing or sunscreen (Makin et al., 2013; Volkov, 2013), suggesting that the decline in melanoma incidence may not be wholly explained by conscious preventive activity by individuals. Strategies targeting educational settings, such as mandated shade provisions in childcare facilities (Ettridge et al., 2011) and extensive SunSmart school policies (Montague et al., 2001), have arguably contributed to success in reducing hazardous sun exposure among minors, although even these strategies have not been implemented with universal effectiveness (Turner et al., 2014).

It is possible that some of the decline in melanoma rates among the young in Australia may be a consequence of secular changes in behavior unrelated to primary prevention activities. Periodic national surveys have documented trends of increasing screen time, less time spent in outdoor play, and fewer children walking or cycling to school (Australian Bureau of Statistics, 2000, 2009), all of which lead to less sun exposure than for previous generations of Australian children (Lucas et al., 2013). In support of the notion that secular changes are leading to lower levels of sun exposure in Australian youth is the observation that the prevalence of myopia (short-sightedness) is rising in many countries, including Australia (Dolgin, 2015; French, Morgan, Burlutsky, et al., 2013a). Because myopia is causally associated with lack of outdoor play (French, Morgan, Mitchell, and Rose, 2013; He et al., 2015; Sherwin et al., 2012), these myopia data suggest that modern children spend less time playing outdoors than previous generations. Such an explanation would fit with cohort-specific changes in melanoma incidence and accord with the notion that sun exposure in childhood is particularly important for initiating melanoma development (Whiteman et al., 2001). The effects of decreased outdoor play on subsequent melanoma incidence may be more noticeable in low-latitude environments such as Australia, where high solar dosages are accumulated through year-round incidental exposures (Diffey and Gies, 1998; Green et al., 2011), compared with high-latitude countries, where dosage is dominated by summer vacation exposures (Thieden et al., 2004).

The rising rates of melanoma in young and middle-aged adults observed in US whites and UK and Sweden populations may be partly attributable to artificial sources of UV exposure. Tanning lamps became widespread in the 1980s and 1990s, especially among the young (Boldeman et al., 2001; Thomson et al., 2010). At the molecular level, DNA photoproducts can be detected in the urine of human volunteers after sunbed exposure (Kotova et al., 2005), and there is increasing evidence that the UVA wavelengths preferentially emitted by solaria have carcinogenic potential (Abdel-Malek and Cassidy, 2015; Premi et al., 2015; Tewari et al., 2012). It is possible that the full effects of tanning bed exposures on melanoma incidence have not yet been realized. If the recent trends in melanoma incidence in the US and Europe are partly attributable to exposure from tanning beds, then our projections of future melanoma incidence will incorporate the effects of recent exposures to these causal factors. Jurisdictions in Australia (Sinclair et al., 2014), the United States (Guy Jr et al., 2014), and the UK (Pawlak et al., 2012) have enacted legislation to restrict sunbed use by minors, and it will be interesting to see whether these laws have the same impact on melanoma incidence as was observed in Iceland after tanning parlors were regulated in that country (Héry et al., 2010).

The historical trends in melanoma reported here are based on observed data and are unlikely to reflect changes in data capture or reporting (except for the known changes in New

Zealand around 1994). However, a potential limitation to these analyses is the issue of underreporting of melanoma diagnoses to cancer registries. The extent of this problem is difficult to gauge, but it is likely to vary across jurisdictions and may have varied over time. For example, underreporting of melanoma was known to occur in New Zealand before 1994 and has been documented in several US Surveillance, Epidemiology, and End Results registries at various times (Cockburn et al., 2008; Watson et al., 2011). Future projections of melanoma incidence also make assumptions about the trajectories of age-specific rates, as well as assumptions about the future size and age structure of populations. Both sets of estimates are prone to error. Perhaps the most arbitrary assumptions involve the magnitudes of drift for age-specific melanoma rates. We followed an empirical approach (Bray and Moller, 2006; Moller et al., 2003) and tested whether, in each population, the drift parameters in the most recently observed time periods were different from that derived over the total period of observed data. If so, we applied the most recent drift parameter, assuming that future rates are more likely to be influenced by recent than historical trends. The NORDPRED approach further assumes that cancer incidence cannot continue to rise exponentially and so dampens the drift over succeeding time periods based on empirical modeling. This will have contributed to the tendency for all projections to stabilize in the most distant future time periods. In sensitivity analyses, we allowed incidence rates to continue to drift without applying any dampening algorithm; as expected, this led to more extreme projections than those presented here (see Supplementary Figure S1 online).

In conclusion, we found trends of increasing total melanoma incidence in US whites and the UK, Swedish, and Norwegian populations, likely stabilization in New Zealand and decreasing incidence in Australia. In all populations, melanoma incidence is destined to rise steeply among older people for some time, but rates appear to be stabilizing or declining among the young. Nevertheless, the overall numbers of patients being diagnosed with melanoma will increase in the decades ahead, for which health services need to prepare. Primary prevention should remain the cornerstone of melanoma control efforts through pragmatic approaches to reduce harm from unnecessary UV exposures (Melanoma research, 2015).

METHODS

We obtained data on incident invasive melanoma cases (i.e., Clark level II–V) and deaths from melanoma on request from population-based cancer registries in the United States, the UK, Norway, Sweden, Australia, and New Zealand for three decades from 1982–2011. (In situ melanomas were excluded.) Historical and forecast population sizes and structure from 1982–2031 were obtained from national statistics agencies. Thus, US data were obtained from the Surveillance, Epidemiology, and End Results program of the National Cancer Institute (9 registries), currently covering approximately 9.4% of the US population (Surveillance, 2013). We used data for US whites only, because melanoma incidence in other racial groups is very low. The population structure for US whites in the nine Surveillance, Epidemiology, and End Results registries closely approximated that for all US whites; we therefore calculated 9.4% for each age and sex category and used these estimates for the population projections sourced for US whites from the US Census Bureau (United States Census Bureau, 2015). For the UK, we obtained melanoma incidence data from cancer registries in Scotland, Wales, and Northern Ireland and the Office for National Statistics for England (Office for National Statistics, 2015a). Population denominators and projections for the UK were also sourced from the Office for National Statistics (Office for National Statistics, 2015b). Melanoma incidence data and population denominators for Sweden and Norway were sourced from the NORDCAN database (Engholm et al., 2010), and population projections from Statistics Sweden (Statistics Sweden, 2015) and Statistics Norway (Statistics Norway, 2015). Australian melanoma incidence and population data were obtained from the Australian Institute of Health and Welfare (2015) and the Australian Bureau of Statistics (2015). All data for New Zealand were obtained via request from Statistics New Zealand.

We calculated the APC in invasive melanoma incidence for the period of observed data (1982–2011) using the Joinpoint Regression Program (Version 4.0.4, National Cancer Institute, Bethesda, MD, USA) using Hudson's continuous fitting algorithm (Hudson, 1966). We used NORDPRED (Moller et al., 2003) to project melanoma incidence rates for four 5-year time periods from 2012–2016 through 2027–2031. The calculations were based on incidence between 1982 and 2011, aggregated into 5-year time periods and 5-year age groups by sex. This approach extends the standard age-period-cohort model (Osmond, 1985) by including a common drift parameter (Clayton and Schifflers, 1987) and two other modifications which have been validated empirically to improve projections (Moller et al., 2003). The model can be written as $R_{ap} = (A_a + D \cdot p + P_p + C_c)^5$, where R_{ap} is the incidence rate in age group a in calendar period p; A_a is the age component for age group a; D is the common drift parameter, which summarizes the linear component of the trend that cannot be attributed to either period or cohort (Clayton and Schifflers, 1987) (i.e., equivalent to the estimated annual percentage rate of change in incidence for a specific age group); P_p is the nonlinear period component of period p; and C_c is the nonlinear cohort component of cohort c. This approach allows a gradual reduction in the drift parameter, which has the effect of gradually reducing the impact of current trends on projected rates; we reduced the drift by 25%, 50%, and 75% in the second (2017–2021), third (2022–2026), and fourth (2027–2031) prediction periods, respectively. In sensitivity analyses, we varied the extent of attenuation of the drift parameter from no attenuation during follow-up (null) to full attenuation in the first 5 years (full) (see Supplementary Table S3 online).

For each country, the first age group to be included in the regression model was the first age group for which the number of cases exceeded 20 in each of the 5-year observation periods (US whites, 15–19 years; the UK, 10–14 years; Sweden, 15–19 years; Norway, 20–24 years; Australia, 10–14 years; New Zealand, 15–19 years). The predictions for each country were based on the last four observation periods for US whites and the UK and Australia populations and on the last six observation periods for the remaining countries, as determined by the goodness-of-fit test (5% level). For all six countries, the crude rates displayed significant curvature in the prediction base (Norway, $P = 0.0212$; for all other countries, $P < 0.001$), and thus the trend in the last 10 years was used as the drift component to be projected (Moller et al., 2003). For each population, we report crude and age-standardized rates using the United States 2000 standard (Anderson and Rosenberg, 1998). We

calculated the number and proportion of melanoma cases that were attributable to changes in population risk (i.e., changes in age-specific rates over time) and population structure (i.e., changes in the size and age distribution), using 1982–1987 as the baseline (Moller et al., 2002).

Finally, we compared the number of melanomas that were actually observed in each population in the two most recent time periods (2002–2006 and 2007–2011) with the number that would have occurred had melanoma incidence continued on the trajectories experienced during the 20 years before 2002 (Bray and Moller, 2006). To do this, we first estimated the number of melanomas in each population that were expected in 2002–2006 and 2007–2011. We fitted age-period-cohort models for the period of 1982–2002 to calculate the underlying incidence rates and their respective drifts. We then projected melanoma incidence for 2002–2006 and 2007–2011, assuming that the underlying age-specific incidence rates continued to drift on the same trajectory as previously. We then multiplied the expected age-specific incidence rates by the age-specific populations in each time period to calculate the expected numbers of melanomas, which were then compared with the observed numbers of melanomas.

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CONFLICT OF INTEREST
The authors state no conflict of interest.

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SUPPLEMENTARY MATERIAL
Supplementary material is linked to the online version of the paper at www.jidonline.org, and at http://dx.doi.org/10.1016/j.jid.2016.01.035.

REFERENCES
Abdel-Malek ZA, Cassidy P. Dark CPDs and photocarcinogenesis: the party continues after the lights go out. Pigment Cell Melanoma Res 2015;28:373–4.

Anderson R, Rosenberg H. Age standardization of death rates: implementation of the year 2000 standard. Hyattsville, Maryland: National Vital Statistics Reports; 1998.

Australian Bureau of Statistics. Children's participation in cultural and leisure activities (cat. no. 4901.0). Canberra, Australia: Australian Bureau of Statistics; 2000.

Australian Bureau of Statistics. Children's participation in cultural and leisure activities, 2009 (cat. no. 4901.0). Canberra, Australia: Australian Bureau of Statistics; 2009.

Australian Bureau of Statistics. Population Projections, Australia, 2012 (base) to 2101 (cat. no. 3222.0), http://www.abs.gov.au/Ausstats/abs@.nsf/mf/3222.0; 2015 (accessed 3 February 2015).

Australian Institute of Health and Welfare. Cancer Data, http://www.aihw.gov.au/cancer-data/ (accessed 3 February 2015).

Autier P, Koechlin A, Boniol M. The forthcoming inexorable decline of cutaneous melanoma mortality in light-skinned populations. Eur J Cancer 2015;51:869–78.

Baade PD, Youlden DR, Youl P, Kimlin M, Sinclair C, Aitken J. Assessment of the effect of migration on melanoma incidence trends in Australia between 1982 and 2010 among people under 30. Acta Derm Venereol 2015;95:118–20.

Boldeman C, Branstrom R, Dal H, Kristjansson S, Rodvall Y, Jansson B, et al. Tanning habits and sunburn in a Swedish population age 13-50 years. Eur J Cancer 2001;37:2441–8.

Boschi-Pinto C, Lopez AD, Murray CJ, Lozano R, Inoue M. Age standardization of rates: a new WHO standard. GPE Discussion Paper Series: No.31 EIP/GPE/EBD. World Health Organization; 2001.

Bray F, Moller B. Predicting the future burden of cancer. Nat Rev Cancer 2006;6:63–74.

Buller DB, Cokkinides V, Hall HI, Hartman AM, Saraiya M, Miller E, et al. Prevalence of sunburn, sun protection, and indoor tanning behaviors among Americans: review from national surveys and case studies of 3 states. J Am Acad Dermatol 2011;65(5 Suppl. 1):S114–23.

Cancer Institute NSW. NSW skin cancer prevention strategy 2012–15. Sydney: Cancer Institute NSW; 2012.

Centers for Disease Control and Prevention. Sunburn and sun protective behaviors among adults aged 18-29 years–United States, 2000-2010. MMWR Morb Mortal Wkly Rep 2012;61:317.

Clayton D, Schifflers E. Models for temporal variation in cancer rates. II: Age-period-cohort models. Stat Med 1987;6:469–81.

Cockburn M, Swetter SM, Peng D, Keegan TH, Deapen D, Clarke CA. Melanoma underreporting: why does it happen, how big is the problem, and how do we fix it? J Am Acad Dermatol 2008;59:1081–5.

Czarnecki D. The incidence of melanoma is increasing in the susceptible young Australian population. Acta Derm Venereol 2014;94:539–41.

Diffey BL, Gies HP. The confounding influence of sun exposure in melanoma. Lancet 1998;351:1101–2.

Dolgin E. The myopia boom. Nature 2015;519:276–8.

Engholm G, Ferlay J, Christensen N, Bray F, Gjerstorff ML, Klint A, et al. NORDCAN–a Nordic tool for cancer information, planning, quality control and research. Acta Oncol 2010;49:725–36.

Erdmann F, Lortet-Tieulent J, Schüz J, Zeeb H, Greinert R, Breitbart EW, et al. International trends in the incidence of malignant melanoma 1953–2008—are recent generations at higher or lower risk? Int J Cancer 2013;132:385–400.

Ettridge KA, Bowden JA, Rayner JM, Wilson CJ. The relationship between sun protection policy and associated practices in a national sample of early childhood services in Australia. Health Educ Res 2011;26:53–62.

French AN, Morgan IG, Burlutsky G, Mitchell P, Rose KA. Prevalence and 5- to 6-year incidence and progression of myopia and hyperopia in Australian schoolchildren. Ophthalmology 2013;120:1482–91.

French AN, Morgan IG, Mitchell P, Rose KA. Risk factors for incident myopia in Australian schoolchildren: the Sydney adolescent vascular and eye study. Ophthalmology 2013;120:2100–8.

Green AC, Wallingford SC, McBride P. Childhood exposure to ultraviolet radiation and harmful skin effects: epidemiological evidence. Prog Biophys Mol Biol 2011;107:349–55.

Guy Jr GP, Berkowitz Z, Jones SE, O'Malley Olsen E, Miyamoto JN, Michael SL, et al. State indoor tanning laws and adolescent indoor tanning. Am J Public Health 2014;104:e69–74.

Guy Jr GP, Thomas CC, Thompson T, Watson M, Massetti GM, Richardson LC. Vital signs: melanoma incidence and mortality trends and projections—United States, 1982–2030. MMWR Morb Mortal Wkly Rep 2015;64:591–6.

He M, Xiang F, Zeng Y, Mai J, Chen Q, Zhang J, et al. Effect of time spent outdoors at school on the development of myopia among children in China: a randomized clinical trial. JAMA 2015;314:1142–8.

Héry C, Tryggvadóttir L, Sigurdsson T, Ólafsdóttir E, Sigurgeirsson B, Jonasson JG, et al. A melanoma epidemic in Iceland: possible influence of sunbed use. Am J Epidemiol 2010;172:762–7.

Hudson DJ. Fitting segmented curves whose join points have to be estimated. J Am Stat Assoc 1966;61:1097–129.

Iannacone MR, Green AC. Towards skin cancer prevention and early detection: evolution of skin cancer awareness campaigns in Australia. Melanoma Management 2014;1:75–84.

Iannacone MR, Youlden DR, Baade PD, Aitken JF, Green AC. Melanoma incidence trends and survival in adolescents and young adults in Queensland, Australia. Int J Cancer 2015;136:603–9.

IARC Working Group on the Evaluation of Carcinogenic Risks to Humans. A review of human carcinogens. In: IARC monographs. Radiation, vol.

100D. Lyon, France: International Agency for Research on Cancer/World Health Organisation; 2012.

Independent Cancer Taskforce. Achieving world-class cancer outcomes: a strategy for England 2015-2020. London: National Health Service/Cancer Research; 2015.

Kotova N, Hemminki K, Segerback D. Urinary thymidine dimer as a marker of total body burden of UV-inflicted DNA damage in humans. Cancer Epidemiol Biomarkers Prev 2005;14:2868–72.

Lazovich D, Choi K, Vogel RI. Time to get serious about skin cancer prevention. Cancer Epidemiol Biomarkers Prev 2012;21:1893–901.

Lucas RM, Valery P, Mei I, Dwyer T, Pender MP, Taylor B, et al. Sun exposure over a lifetime in Australian adults from latitudinally diverse regions. Photochem Photobiol 2013;89:737–44.

Makin JK, Warne CD, Dobbinson SJ, Wakefield MA, Hill DJ. Population and age-group trends in weekend sun protection and sunburn over two decades of the SunSmart programme in Melbourne, Australia. Brit J Dermatol 2013;168:154–61.

Melanoma research gathers momentum. Lancet 2015;385:2323.

Michielin O, Hoeller C. Gaining momentum: new options and opportunities for the treatment of advanced melanoma. Cancer Treatment Rev 2015;41:660–70.

Moller B, Fekjaer H, Hakulinen T, Sigvaldason H, Storm HH, Talback M, et al. Prediction of cancer incidence in the Nordic countries: empirical comparison of different approaches. Stat Med 2003;22:2751–66.

Moller B, Fekjaer H, Hakulinen T, Tryggvadottir L, Storm HH, Talback M, et al. Prediction of cancer incidence in the Nordic countries up to the year 2020. Eur J Cancer Prev 2002;11(Suppl. 1):S1–96.

Montague M, Borland R, Sinclair C. Slip! Slop! Slap! and SunSmart, 1980-2000: skin cancer control and 20 years of population-based campaigning. Health Educ Behav 2001;28:290–305.

Nilsen LT, Aalerud TN, Hannevik M, Veierod MB. UVB and UVA irradiances from indoor tanning devices. Photochem Photobiol Sci 2011;10:1129–36.

Nilsen LT, Hannevik M, Aalerud TN, Johnsen B, Friberg EG, Veierod MB. Trends in UV irradiance of tanning devices in Norway: 1983-2005. Photochem Photobiol 2008;84:1100–8.

Office for National Statistics. Melanoma Incidence Data 1982-2011. http://www.ons.gov.uk/ons/about-ons/business-transparency/freedom-of-information/what-can-i-request/published-ad-hoc-data/health/february-2015/index.html; 2015a (accessed 10 February 2015).

Office for National Statistics. UK Population Single Year 2012 to 2112. http://www.ons.gov.uk/ons/taxonomy/index.html?nscl=Population#tab-data-tables; 2015b (accessed 12 February 2015).

Osmond C. Using age, period and cohort models to estimate future mortality rates. Int J Epidemiol 1985;14:124–9.

Pawlak MT, Bui M, Amir M, Burkhardt DL, Chen AK, Dellavalle RP. Legislation restricting access to indoor tanning throughout the world. Arch Dermatol 2012;148:1006–12.

Premi S, Wallisch S, Mano CM, Weiner AB, Bacchiocchi A, Wakamatsu K, et al. Photochemistry. Chemiexcitation of melanin derivatives induces DNA photoproducts long after UV exposure. Science 2015;347:842–7.

Sherwin JC, Reacher MH, Keogh RH, Khawaja AP, Mackey DA, Foster PJ. The association between time spent outdoors and myopia in children and adolescents: a systematic review and meta-analysis. Ophthalmology 2012;119:2141–51.

Sinclair CA, Makin JK, Tang A, Brozek I, Rock V. The role of public health advocacy in achieving an outright ban on commercial tanning beds in Australia. Am J Pub Health 2014;104:e7–9.

Statistics Norway. Population Projections 2014-2100. http://www.ssb.no/en/befolkning/statistikker/folkfram/aar/2014-06-17?fane=tabell#content; 2015 (accessed 10 March 2015).

Statistics Sweden. Current projection of population. Population Size 31 Dec by Age, Sex and Year. http://www.scb.se/en_/Finding-statistics/Statistics-by-subject-area/Population/; 2015 (accessed 13 February 2015).

Surveillance, Epidemiology, End Results (SEER) Program. SEER*Stat Database: Incidence—SEER 9 Registries Research Data, Nov 2013 Sub (1973-2011). Katrina/Rita Population Adjustment. http://www.seer.cancer.gov; 2013 (accessed 12 February 2015).

Tewari A, Sarkany RP, Young AR. UVA1 induces cyclobutane pyrimidine dimers but not 6-4 photoproducts in human skin in vivo. J Invest Dermatol 2012;132:394–400.

Thieden E, Philipsen PA, Sandby-Moller J, Heydenreich J, Wulf HC. Proportion of lifetime UV dose received by children, teenagers and adults based on time-stamped personal dosimetry. J Invest Dermatol 2004;123:1147–50.

Thomson CS, Woolnough S, Wickenden M, Hiom S, Twelves CJ. Sunbed use in children aged 11-17 in England: face to face quota sampling surveys in the National Prevalence Study and Six Cities Study. Br Med J 2010;340:c877.

Turner D, Harrison SL, Buettner P, Nowak M. School sun-protection policies-does being SunSmart make a difference? Health Ed Res 2014;29:367–77.

United States Census Bureau. 2014 National Population Projections: Downloadable Files. Table 1. Projected population by single year of age, sex, race, and Hispanic origin for the United States: 2014 to 2060. http://www.census.gov/population/projections/data/national/2014/downloadablefiles.html; 2015 (accessed 15 February 2015).

US Department of Health and Human Services. The Surgeon General's call to action to prevent skin cancer. Washington, DC: US Department of Health and Human Services, Office of the Surgeon General; http://www.surgeongeneral.gov/library/calls/prevent-skin-cancer; 2014.

Volkov A, Dobbinson S, Wakefield M, Slevin T. Seven-year trends in sun protection and sunburn among Australian adolescents and adults. Aust N Z J Public Health 2013;37:63–9.

Watson M, Johnson CJ, Chen VW, Thomas CC, Weir HK, Sherman R, et al. Melanoma surveillance in the United States: overview of methods. J Am Acad Dermatol 2011;65:S6–16.

Watts C, Reeder A, Glasgow H. A cover-up story: the Cancer Society Melanoma Prevention programme. In: McKenzie R, Reisinger A, Watts C, editors. UV radiation and its effects – an update 2002. Christchurch, NZ: Royal Society of New Zealand; 2002. p. 1–3.

Weir HK, Marrett LD, Cokkinides V, Barnholtz-Sloan J, Patel P, Tai E, et al. Melanoma in adolescents and young adults (ages 15-39 years): United States, 1999-2006. J Am Acad Dermatol 2011;65:S38–49.

Whiteman DC, Whiteman CA, Green AC. Childhood sun exposure as a risk factor for melanoma: a systematic review of epidemiologic studies. Cancer Causes Control 2001;12:69–82.