Estimating the potential economic impacts of climate change on Southern California beaches

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Abstract Climate change could substantially alter the width of beaches in Southern California. Climate-driven sea level rise will have at least two important impacts on beaches: (1) higher sea level will cause all beaches to become more narrow, all things being held constant, and (2) sea level rise may affect patterns of beach erosion and accretion when severe storms combine with higher high tides. To understand the potential economic impacts of these two outcomes, this study examined the physical and economic effects of permanent beach loss caused by inundation due to sea level rise of one meter and of erosion

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and accretion caused by a single, extremely stormy year (using a model of beach change based on the wave climate conditions of the El Niño year of 1982/1983.) We use a random utility model of beach attendance in Southern California that estimates the impacts of changes on beach width for different types of beach user visiting public beaches in Los Angeles and Orange Counties. The model allows beachgoers to have different preferences for beach width change depending on beach size. We find that the effect of climate-driven beach change differs for users that participate in bike path activities, sand-based activities, and water-based activities. We simulate the effects of climate-related beach loss on attendance patterns at 51 public beaches, beach-related expenditures at those beaches, and the non-market (consumer surplus) value of beach going to those beaches. We estimate that increasing sea level will cause an overall reduction of economic value in beach going, with some beaches experiencing increasing attendance and beach-related earnings while attendance and earnings at other beaches would be lower. We also estimate that the potential annual economic impacts from a single stormy year may be as large as those caused by permanent inundation that would result from a rise in sea level of one meter. The economic impacts of both permanent inundation and storm-related erosion are distributed unevenly across the region. To put the economic impacts of these changes in beach width in perspective, the paper provides simple estimates of the cost of mitigating beach loss by nourishing beaches with sand.

1 Introduction

Always dynamic, California's coasts will certainly be altered by natural forces over the next 100 years. Increases in sea level will likely affect beaches through permanent inundation (the loss of beach due simply to flooding when beaches cannot migrate shoreward) and increasingly intense erosion and accretion when higher high tides interact with severe storms (Cayan et al. 2008). These beaches also are important to home owners who depend on beaches to protect their homes from storm surge, for public infrastructure (especially roads), and to the millions of Californians who use beaches as an important destination for outdoor recreation (Neumann and Hudgens 2006).

Of the many potential economic impacts that may result from the impacts of climate change on beaches, we focus on the effects of sea level rise on the beach-going economy of Southern California. We use a recently developed model of beach choice by day users in Southern California to demonstrate how predictions about future impacts of sea level rise on beaches can be linked to detailed economic models of beach recreation behavior. Our analysis is not intended to provide precise estimates of the impact of climate change on Southern California beach attendance. Our goal, rather, is to develop a framework that demonstrates how to link estimates of beach change (changes in width and volume of sand) caused by sea level rise to economic models of beach attendance, expenditures, and consumer surplus. This is a first step toward evaluating the effects of climate-related beach change on the net economic value of beaches in Southern California.

To illustrate our framework, and the potential magnitude of the economic impacts of sea level rise, we use an economic analysis based on projections of beach width change from permanent inundation due to 1 m (m) of sea level rise and beach width and area change due to an extremely stormy year. We recognize that sea level, and thus beach width, change constantly over the course of a day, a lunar cycle, a year, and over decades. We explore "permanent" inundation as a means of thinking about average loss in beach width that could occur due to a rise in average sea level. Projections of beach width change due to

permanent inundation is estimated based on beach slope data (Hapke et al. 2006) and beach width and volume change due to large storms are based on a new model of beach sediment budgets being developed by Adams and Inman (2009), applied to sites in Southern California (Adams et al. 2011). This geomorphic model, the Coastal Erosional Hotspot Potential Model (referred to subsequently as the CEHP) is in its early stages of development. Indeed, we view their results as indicators of the order of magnitude of the potential impacts on beaches that could be associated with extremely stormy years. Our methods can easily be applied to a variety of models that project future beach width.

Beach width has been shown to be an important determinant of where day use visitors go to the beach in Southern California (Pendleton et al. 2008) and is one of the primary explanatory variables in a model of beach choice for Southern California public beaches (originally developed by Hanemann et al. 2005 and recently updated by Pendleton et al. 2011). While tourism to beaches may also be affected by beach width, the models of Hanemann et al. and Pendleton et al. examine beach going only for Southern California residents. Hanemann et al. showed that more than 50% of all households in Los Angeles, Orange, Riverside, and San Bernardino counties had at least one member who went to the beach over the course of a year. This large population of users may account for more than 100 million visits to local beaches annually (Pendleton and Kildow 2006.)

Sea level rise in California, as measured by tide gauges has risen at a rate of 17–20 cm per century (Cayan et. al. 2009), nearly as much as global SLR. Rahmstorf (2007) and others have linked sea level rise to increases in mean surface air temperature, providing a technique for forecasting future increases in sea level rise.

We use Adams and Inman's estimates of potential changes in beach width, and the beach choice model of Pendleton et al. (2011) to model the effects of a 1 m rise in sea level on beach attendance, beach expenditures, and the non-market value of beach going—the economic value of beaches to local beachgoers, beyond what they have to pay to use the beach. To provide perspective for our estimates of the impacts of steady rise in sea level, 1 m over 100 years, we also model the potential impacts on beach width due to a year of unusually intense storm events. In our case, we use the storm events from the El Niño years of 1982 and 1983. In addition to sea level rise, it is thought that deep-water wave fields are changing in accordance with global climate phenomena, such as the El Nino-Southern Oscillation (ENSO) and the Pacific Decadal Oscillation (PDO) (Adams et al. 2008). Because coastal managers may choose to counter permanent inundation and extreme erosion events, we also provide simple, but illustrative, estimates of the costs of physically renourishing beaches, by placing new sand on beaches, following such events.

1.1 Economic value of Southern California beaches

Beaches are an important recreational resource enjoyed by residents of California and many visitors to the state. According to The National Survey of Recreation and the Environment (NSRE) in 2000, nearly 15 million people participated in beach activities in California. This dominates all other forms of marine recreation in the state but is still an underestimate because foreign tourists were not included in the survey.

California residents spend $4 billion annually on beach recreation (Pendleton and Kildow 2006). Many local visitors are able to enjoy the beach at little or no cost, but they enjoy considerable economic benefit from their presence. This benefit is called the *consumer surplus* or *non-market value* of beaches and represents the willingness to pay to visit beaches, beyond what people actually do pay. These non-market values are real and generally come to public attention when beaches are damaged (either through beach loss or

deterioration of water quality) or removed from use (e.g., due to an oil spill). The non-market value of beaches has been evaluated numerous times in the literature and has been estimated to contribute more than $2 billion to the economic well-being of Californians (Pendleton and Kildow 2006).

The billions of dollars spent by beachgoers contribute to a number of local economic activities. Day visitors to beaches spend money locally on food, beverages, parking, and beach-related activities and rentals (e.g., body boards, umbrellas). Such purchases partially represent a transfer of expenditures that may have been made elsewhere in the state (e.g., gas and auto), but are largely expenditures that would not have been made in the absence of the beach trip. King (1999) estimated the fiscal impact of beaches in California and reported that in 1998, California's beaches generated $14 billion dollars in direct revenue (King 1999).[1] In two other studies, the average expenditures per person per day trip ($/trip/person) were estimated for visits to California beaches at between $23 and $29 per day (see Pendleton and Kildow 2006 for a review.) Such numbers may appear small when compared to alternative activities, such as amusement parks, but with annual daily visits in the millions, it all adds up to a multi-billion dollar, renewable resource.

1.2 Impact of climate change on beach economies in Southern California

The market and non-market (consumer surplus) values that are generated by beach recreation can be affected by the quality of the coastal environment. Obvious problems such as trash on the beach clearly deter visitors, but beach width is an important factor as well (Lew 2005; Lew and Larson 2006; Bin et al. 2007). Pendleton et al. (2011) show that different users prefer different beach widths, depending on the type of recreation they plan to undertake (e.g., sand-based versus water-based versus pavement-based activities). Changes in the width of beaches due to permanent inundation or storms could change beach attendance substantially. As beach attendance changes, so do local expenditures and non-market value.

For Southern California, climate change may physically affect beaches through at least two mechanisms: (1) permanent beach loss due to inundation caused by sea-level rise, and (2) increased intensity of storms caused by higher high tides (California Coastal Commission 2001; Cayan et al. 2005, 2006). Inherently dynamic, beaches can be eroded very quickly if the rate of sand removal through erosion surpasses the rate of replenishment through accretion. In fact, several studies have indicated a net global loss in beach area over the last 100 years (Bird 1985; NRC 1990; Leatherman 2001; Eurosion 2004) and beaches are expected to shrink more rapidly because of sea-level rise (Brown and McLachlan 2002).

In Southern California, storm events and wave action also contribute substantially to coastal erosion (Flick 1998; Seymour et al. 2005). Storm surges, or waves of extraordinary height that occur during storms (especially storms that coincide with high tides), can be amplified by sea level rise, increasing their destructive power (Cayan et al. 2008). It also is possible that changes in wave climate (e.g., wave direction, height, and period) could have erosional effects on beaches, but evidence suggests that this factor will be much more important at higher latitudes (Allan and Komar 2006; Flick and Bromirski 2008), except when exacerbated by the El Niño Southern Oscillation (ENSO) cycle (e.g., Seymour et al. 1984; Inman and Jenkins 1998).

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[1] *Direct revenue* is the direct expenditure from people making beach trips for items such as gas and parking, food and drinks from stores, restaurants, equipment rentals, beach sporting goods, beach-related lodging, and incidentals.

While efforts have been made to estimate the overall coastal impacts of climate change in California (see for instance Neumann and Hudgens 2006 and more recently by Heberger et al. 2009), no attempt has been made to examine carefully the impacts of sea level rise due to climate change on the beach going economy of the state. In a report to the California Department of Boating and Waterways, King and Symes (2003) determined that failure to protect Southern California beaches would reduce the California gross state product by over $5.5 billion annually. However, their data reflects changes in use based on the complete absence of beaches in the area, rather than losses specifically due to sea level rise. Cost estimates for previous extremely stormy years, such as the 1997–1998 El Niño, have been estimated at about $1.1 billion for California as a whole (Andrews cited as personal communication in Changnon 2000). In addition to changes in the amount beachgoers spend, climate change-induced alterations of beaches in Southern California could also reduce the consumer surplus that local beachgoers enjoy from having easy access to hundreds of miles of beaches. As noted above, the non-market value of beach going can be quite large.

Section 2 describes our methods. We provide analysis for our results in Section 3. Implications for coastal management in Southern California are presented in Section 4.

2 Methods

Our work links three different types of analysis: a beach attendance model that estimates how beachgoers in Southern California choose among 51 public beaches, the CEHP, which models erosion and accretion patterns for beaches, and an analysis of beach nourishment costs (Fig. 1). The beach model predicts beach attendance patterns based on certain demographic features of potential beachgoers, the cost of travel, and the attributes of beaches, including beach width. Projections of changes in beach width due to permanent inundation are calculated by averaging beach slopes to find the average slope for each of our 51 beaches. We then combine slopes and sea level rise (1 m) to estimate lost beach width. Since sea level rise could increase the erosion and accretion potential of winter
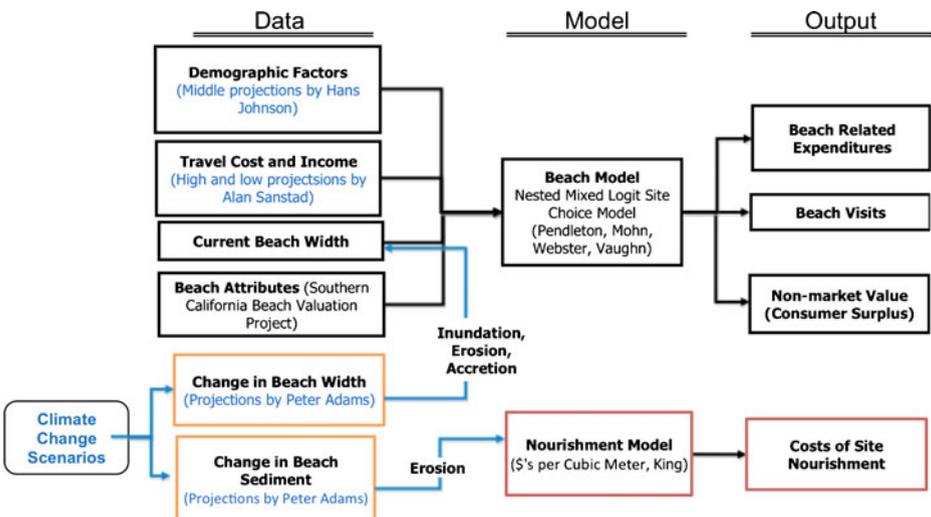
Fig. 1 Dataflow for economic impacts of climate change on Southern California beaches

storms when storms coincide with elevated high tides, we also estimate the impacts of a highly stormy year. To estimate the changes in beach width due to erosion and accretion caused by an extremely stormy year, we use preliminary results from the CEHP model to estimate the effects of the wave climate from El Niño (1982–1983). Finally, we estimate the costs of replacing sand volume lost to permanent inundation or storm-related erosion. In both cases, beach width data and sand volume loss or gain data are provided by estimates from the beach sediment model. We briefly describe each of the three analyses below.

2.1 Beach choice and attendance model

Many factors influence where and when residents of Southern California decide to go to the beach. These include personal factors (e.g., income, age, gender, etc.), the cost of travel, and the different attributes of beaches (e.g., water quality, parking, etc.). Beach width is one of many attributes. Our model predicts the number of visitors, from each census block in four counties in Southern California (Los Angeles, Orange, Riverside, and San Bernardino). Changes in attributes can also affect the visitor's economic well-being of beachgoers by making beaches more or less enjoyable. In simpler terms, non-market benefits measure a visitor's willingness to pay for the experience of the beach. Our paper measures how this non-market value (also referred to as consumer surplus) changes with beach width. Our model also measures the economic impacts of these changes, i.e., how consumer's spending changes when they shift their beach visitation patterns (e.g., buying lunch or gas at Huntington City beach as opposed to another beach).

2.1.1 Data used in model estimation

To simulate the impact of changes in beach width on beach-going activity, Pendleton et al. (2011) modified the original Southern California Beach valuation model of Hanemann et al. 2005. This study contained detailed survey data on beach visitation patterns and demographics. Travel costs were estimated based on respondent location and income was valued at one-half the respondent's hourly income. Data on 46 beach attributes were obtained by site visits (for more detailed discussions of the data see Hanemann et al. 2005 or Pendleton et al. 2011).The authors use beach width measurement data to re-estimate a Random Utility Model (Hanemann et al. 2004) of beach choice (Fig. 2).

Finally, Pendleton et al. (2011) collected data to estimate the width of each beach site from the wet sand to the back of the beach (i.e., the "dry beach"). Using aerial photographs and digital orthophotography quadrangle images from the United States Geological Survey (USGS), the researchers estimated measurements of width (in meters) at 20 m transects along the entire length of each site identified in our study.

2.1.2 Formulation of the beach choice model

As noted above, a user's response to changes in beach width depends on the choice of beach activities. Pendleton et al. (2011) divide the trip data into three activity categories: (1) getting in the water (e.g., swimming), (2) actively using the sand (e.g., volleyball), or (3) activities using paved trails, sidewalks, or beachfront restaurants. A panelist may engage in different activities on different trips.

Pendleton et al. (2011) sequentially model three (nests of) choices for the beachgoers' decision: (1) whether or not to make a trip to the beach, (2) the activity to undertake at the beach, and (3) the beach to visit based on the option which offers the highest utility (see
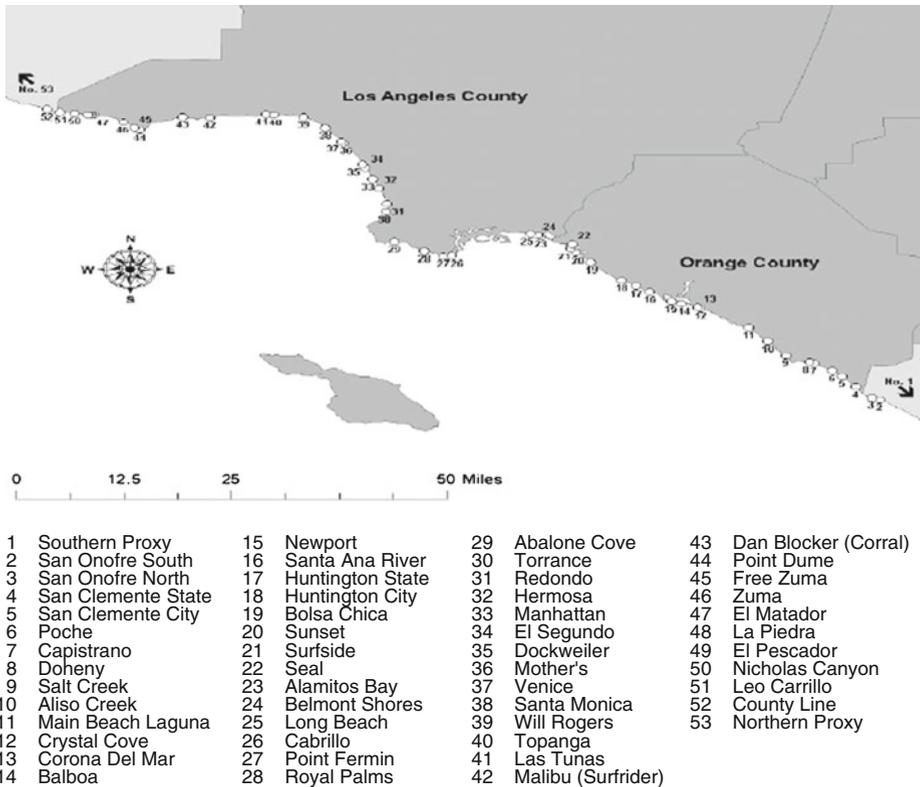
Fig. 2 Location of Southern California beaches covered in this study

1 Southern Proxy	15 Newport	29 Abalone Cove	43 Dan Blocker (Corral)
2 San Onofre South	16 Santa Ana River	30 Torrance	44 Point Dume
3 San Onofre North	17 Huntington State	31 Redondo	45 Free Zuma
4 San Clemente State	18 Huntington City	32 Hermosa	46 Zuma
5 San Clemente City	19 Bolsa Chica	33 Manhattan	47 El Matador
6 Poche	20 Sunset	34 El Segundo	48 La Piedra
7 Capistrano	21 Surfside	35 Dockweiler	49 El Pescador
8 Doheny	22 Seal	36 Mother's	50 Nicholas Canyon
9 Salt Creek	23 Alamitos Bay	37 Venice	51 Leo Carrillo
10 Aliso Creek	24 Belmont Shores	38 Santa Monica	52 County Line
11 Main Beach Laguna	25 Long Beach	39 Will Rogers	53 Northern Proxy
12 Crystal Cove	26 Cabrillo	40 Topanga	
13 Corona Del Mar	27 Point Fermin	41 Las Tunas	
14 Balboa	28 Royal Palms	42 Malibu (Surfrider)	

Fig. 3). The model assumes beachgoers choose the beach that maximizes their utility. The authors use a nested multinomial logit model to analyze the tradeoffs that drive the consumption decision.

Following Train (1998), we use a logarithmically transformed size factor in the application of random utility models to recreational site choice. Pendleton et al. (2011) use
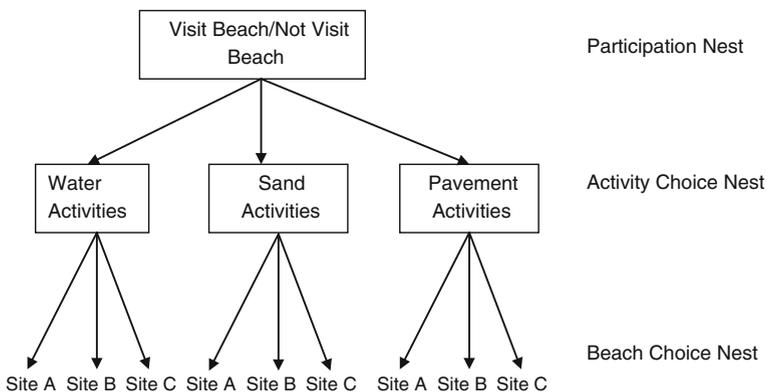
Fig. 3 Beach choice model structure

a simple nested logit structure rather than a mixed-logit (random parameter) model because it provides more control over the choice structure of the model and allows for the use of data for which trip detail may be incomplete (e.g. the respondent may have reported where they visited, but not what they did).

2.2 Width projections

Climate change affects beach width in at least two ways: (1) through permanent beach width loss caused by inundation, and (2) through a change in sediment budgets caused by a changes in deep water wave heights, periods, and directions (a.k.a. wave climate), which alters beach sediment volume. These projections were provided by the CEHP model (Adams and Inman 2009; Adams et al. 2011) and cover scenarios of (1) a 1 m rise in sea level, and (2) the erosion and accretion patterns associated with an extremely stormy year (the El Niño year of 1982/1983).

We used beach slope values, estimated from a Light Detection and Ranging (LIDAR) data set compiled by Hapke et al. (2006) to estimate the potential loss of beach width. We assume permanent inundation occurs gradually across the study period. Adams and Inman (2009) also use computer models to estimate sediment budgets (measured as volume of sand deposited or removed) in cells that are 100 m wide for the length of coast extending from County Line Beach in Ventura County to San Onofre State Park in San Diego County. By 2100, a minimum of 1 m of sea level rise is expected to reduce the average widths of all beaches in Southern California, though some will be affected more than others. Average loss of width for all beaches is estimated to be approximately 9 m, which represents a range from −6 m (County Line) to −16 m (Santa Ana River). Sea level rise also will make the erosion and accretion effects of winter storms more severe

2.3 Demographic and economic projections

Changes in population size, demographics, and the cost of travel could seriously affect beach attendance in the coming century. Our analysis also explores how several demographic and economic factors may interact with sea level rise to alter beach going over time. The most important of these are average household income, gender, race, employment, and projections of estimated travel costs per mile. Hans Johnson (estimates provided by the California Energy Commission) and Alan Sanstad (memo, July 2, 2008) developed scenarios for use in the beach choice model. Table 1 summarizes these contributions and the six scenarios generated for beach attendance and expenditure.

Table 1 Beach choice model width and socioeconomic scenarios

Sea level rise (Adams and Inman)	Demographic changes (Hans Johnson)	Income and travel costs (Alan Sanstad)	
Current sea level (baseline)	Current	Current	Scenario 1
	Midrange predictions	Maximum expected	Scenario 2
		Minimum expected	Scenario 3
Plus 1 m sea level rise (expected with climate change)	Current	Current	Scenario 4
	Midrange predictions	Maximum expected	Scenario 5
		Minimum expected	Scenario 6

Alan Sanstad, from the Lawrence Berkeley National Laboratory, provided projections of two important economic indicators: household income and travel costs. He used the Intergovernmental Panel on Climate Change's *Special Report on Emissions Scenarios* (SRES, Nakicenovic and Stewart 2000) A2 and B1 global scenarios to derive "lower" and "higher" expected values for household income and the cost of driving over 10-year intervals from 2010 to 2100. Both economic indicators affect beach choice.

The population for Los Angeles, Riverside, San Bernardino, and Orange counties is predicted to change dramatically over the course of the next century. Even moderate assumptions regarding fertility and immigration result in a doubling of the regional population from approximately 17 million in 2005 to 32 million in 2100.

3 Results

3.1 Estimated annual economic impact caused by permanent beach loss from inundation due to sea level rise

The economic impacts of permanent beach width loss and even a single stormy year are large and unevenly distributed across the region. Inundation due to sea level rise has only a modest impact on total beach attendance to the region. Holding population and demographic conditions fixed at year 2000 levels, a 1 m rise in sea level increases the total annual attendance at beaches in Los Angeles and Orange counties by 589,000 visits, a relatively small percentage. However, although the relative change in annual visits may be small, the overall change in consumer surplus is substantial (Fig. 4) since the erosion of beach width substantially reduces the recreational value of a beach day and induces some visitors to drive farther to reach a beach with the desired width
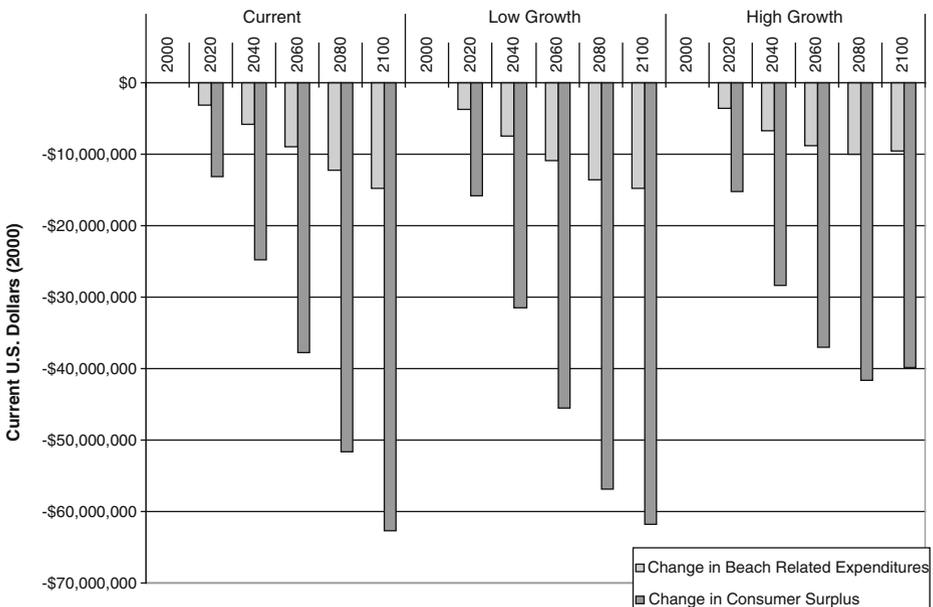
Fig. 4 Change in annual expenditures and annual consumer surplus with +1 m sea level rise: 2000–2100

Changes in the number of beach visits made annually will also affect the amount of money beachgoers spend on beach-related activities and the amount of consumer surplus that they enjoy. Even relatively small overall expected differences in attendance can have a large economic impact. As shown in Fig. 4, compared to scenarios of no sea level rise, estimated direct expenditures on beach-related activities are almost $10 million lower annually under the high growth scenario, and almost $15 million lower annually under the low growth and no change scenarios. Consumer surplus—the reduction in visitors willingness to pay to go to the beach—will be even more affected. Permanent beach loss, caused by sea level rise, may cause the loss in consumer surplus to be as much as $40 million annually under the high growth scenario and more than $60 million under the low growth and no growth scenarios.

3.1.1 The uneven impact of permanent beach loss, due to inundation, on beaches

Beach width and attendance at Southern California beaches has never been uniform; beaches that are more accessible, wider, and provide more amenities tend to draw larger numbers of visitors. Figure 5 depicts the expected beach visits over time with a gradual +1 m sea level rise under the "Current" economic scenario. In this case, all variation results from changes in width due to sea level rise. Even when the absolute loss of beach width is substantial (e.g., >10 m), very large beaches tend to remain large, even with permanent inundation due to sea level rise. As a result, visitors tend to substitute away from already small beaches that have eroded further to beaches that remain large. For example, Newport, Huntington City, and Manhattan beaches will have even higher levels of attendance with sea level rise, while visits to other popular beaches like Huntington State, Venice, and Santa Monica beaches are not expected to differ substantially. Other, relatively small beaches show lower levels of attendance with sea level rise, including Laguna, Bolsa Chica, Torrance, and Redondo beaches.

The differences in beach attendance due to permanent beach loss alone are much more pronounced when we examine the effects at individual beaches. "Winners," or beaches that receive increasing numbers of visitors as sea levels rise, can also expect higher local beach-related expenditures, since people spend about US$25.18 per trip to the beach (year 2000$, Pendleton and Kildow 2006). On the other hand, "Losers," or those beaches where visits are predicted to be fewer, can expect lower beach-related expenditures and thus earnings. The magnitude of such differences is indicated in Table 2, which lists the top five winners and losers when sea level rise is the only factor that is allowed to vary in the model. As a result of complex interactions between beach attributes and sea level rise, beaches like Huntington City and Will Rogers can expect big gains but others such as Laguna and Bolsa Chica can expect big losses with sea level rise.

Losses in the welfare of beachgoers will be also felt differentially across the region. Table 3 lists changes in consumer surplus for residents by their county of origin.

3.1.2 High growth vs. low growth with inundation

As noted above, we do not expect that all other factors will remain constant over the next 100 years. Therefore we also analyzed the impact of sea level rise under two additional socioeconomic scenarios: one in which there is "Low Growth" in income and travel costs and middle projections of growth in population and demographics and another in which there is "Higher Growth." The relative change in attendance, expenditures, and consumer

a

Orange County Beaches (South to North)

b

Los Angeles County Beaches (South to North)
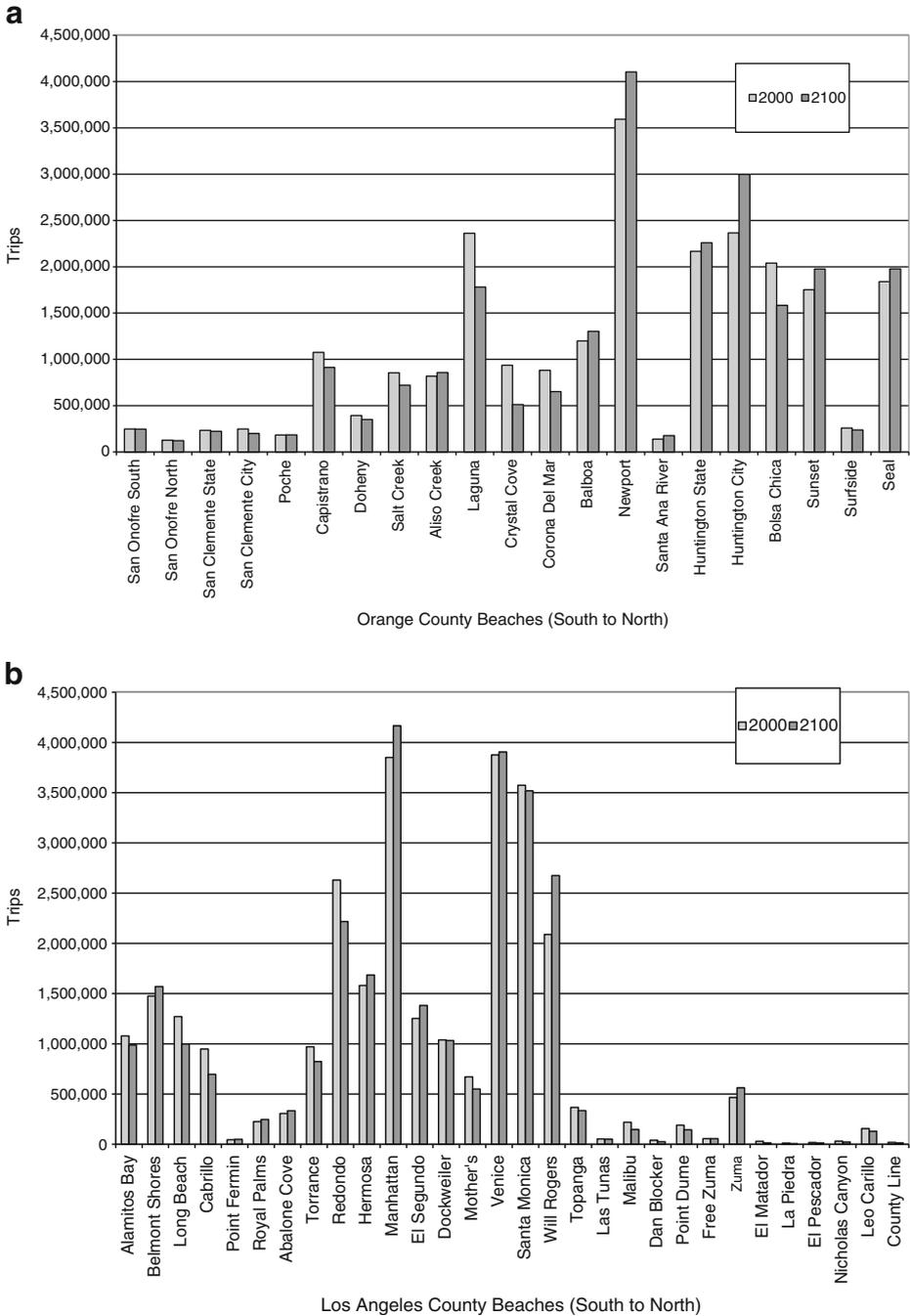
Fig. 5 Attendance by beach width 2100 (projected with 1 m sea level rise) vs. 2000 (measured)

surplus at beaches caused by permanent beach loss follows a similar pattern for all scenarios of economic change, only the magnitude of impacts differs. Gains or losses in

Table 2 Top 5 winners and losers with 1 m sea level rise (current demographic, population, and costs)

Winners	Difference in annual expenditures US$(2000), rounded to nearest million	Losers	Difference in annual expenditures US$(2000), rounded to nearest million
Huntington City	16 million	Main Beach Laguna	−14 million
Will Rogers	15 million	Bolsa Chica	−12 million
Newport	13 million	Crystal Cove	−11 million
Manhattan	8 million	Redondo	−10 million
Sunset	6 million	Long Beach	−7 million

2100 tend to be smaller in the Low Growth scenario than they are in the Current scenario. High economic growth has a greater impact, resulting in even lower final annual attendance estimates.

As before, even under these different scenarios of population and economic change, some beaches have fewer visitors with 1 m of sea level rise while others have more visitors when beaches are permanently inundated due to sea level rise (see Table 4). Losses due to sea level rise are less severe when economic growth is factored into the model. Furthermore, this effect is much more pronounced under the high growth scenario. Compared to either no growth or low growth, change in expenditures by beach due to sea level rise is reduced by half when high growth is assumed.

Changes in expenditures follow similar patterns under the low and high scenarios. Figure 6 compares change in beach-related expenditures due to permanent beach loss caused by sea level rise in the three socioeconomic scenarios. The differences in economic impacts, by county in which the beach is located, are largest with current population, income, and travel costs. Losses are twice as great for Orange County compared to Los Angeles County beaches. However, when economic and demographic projections are factored into the model, the difference between expected expenditures with climate change compared to the baseline is smaller for Orange County. In fact, under either high or low growth, the difference between projected expenditures and the baseline are smaller in the future for Orange County beaches. This is likely due to the difference in population and growth projections for these and neighboring counties.

Table 3 Difference in annual consumer surplus caused by permanent beach loss, due to inundation, from +1 m sea level rise (US$[2000], rounded to nearest million)

	Los Angeles	Orange	Riverside	San Bernardino
Consumer surplus (estimated for county of beachgoer residence)				
2020	−7 million	−4 million	−1 million	−1 million
2040	−12 million	−7 million	−3 million	−2 million
2060	−19 million	−11 million	−4 million	−4 million
2080	−26 million	−15 million	−6 million	−5 million
2100	−31 million	−19 million	−7 million	−6 million

Table 4 Top five winners and losers for permanent beach loss due to 1 m inundation, two socioeconomic scenarios

Winners	Difference in annual expenditures US$[2000], rounded to nearest million	Losers	Difference in annual expenditures US$[2000], rounded to nearest million
Low growth			
Huntington City	14 million	Bolsa Chica	−13 million
Newport	13 million	Laguna	−13 million
Will Rogers	12 million	Redondo	−10 million
Manhattan	8 million	Crystal Cove	−8 million
Sunset	5 million	Long Beach	−7 million
High growth			
Huntington City	7 million	Bolsa Chica	−8 million
Newport	7 million	Laguna	−6 million
Will Rogers	6 million	Redondo	−6 million
Manhattan	5 million	Mother's	−5 million
Sunset	3 million	Long Beach	−5 million

Consumer surplus loss due to permanent beach loss caused by sea level also differs by county (Fig. 7). Residents from Los Angeles County bear the greatest burden in lost consumer surplus, which is over $30 million lower with a 1 m rise in sea level under the current and low growth scenarios and by almost $25 million in the high growth scenario.
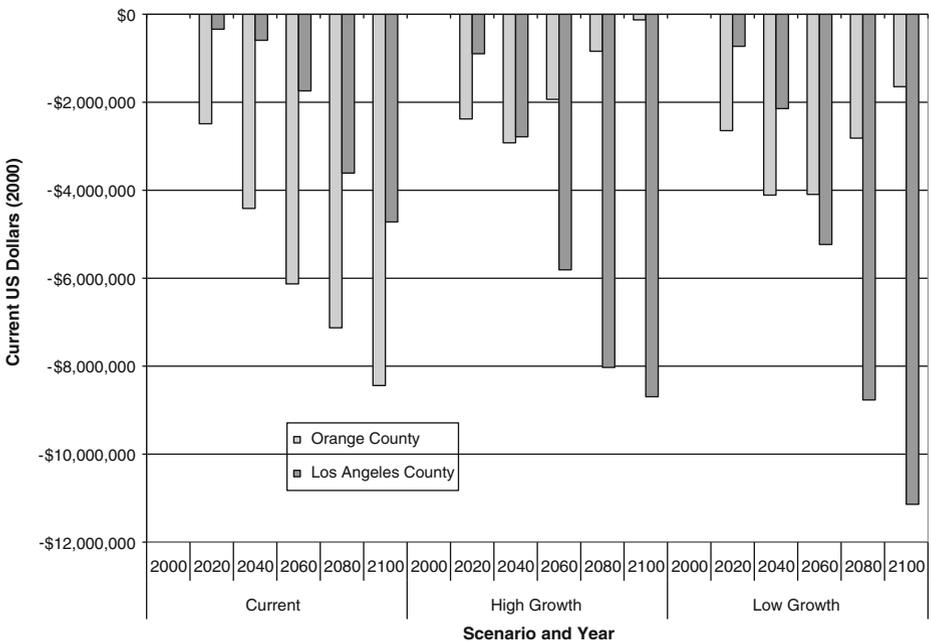
Fig. 6 Difference in expenditure with +1 m sea level rise by county under three scenarios: 2000–2100
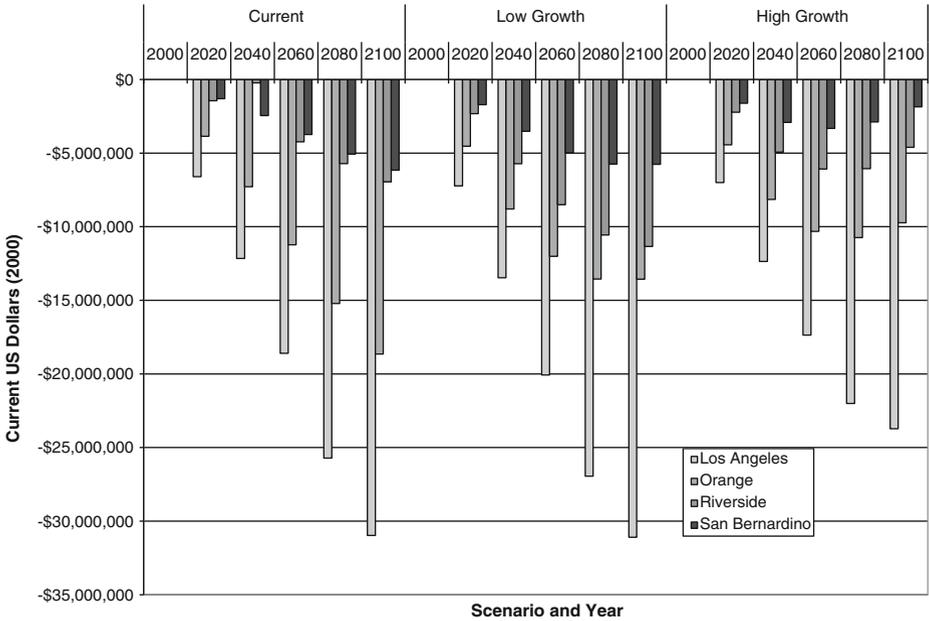
Fig. 7 Difference in consumer surplus due to +1 m rise in sea level under three scenarios: 2000–2100

Orange County experiences smaller differences in consumer surplus in the two growth scenarios, but Riverside County would experience its highest losses under the low growth scenario. San Bernadino suffers least in all three scenarios.

3.2 The economic impact of extremely stormy years

Of course, the effects of sea level rise on beach width are unlikely to occur slowly and evenly across the region. While wave characteristics may not change substantially due to climate change, sea level rise will increase water levels associated with high tides and these elevated water levels are likely to exacerbate the effects of wintertime storms on beach erosion and accretion (Cayan et al. 2008). To explore the potential economic impacts of erosion and accretion caused by extremely stormy years, we investigate the economic impacts of beach change simulated for a year similar to the 1982–1983 El Niño. These estimates are intended only to show how these extreme years compare to the assumption of simple inundation. We do not have good estimates, at this time, of how sea level rise and winter storms will affect beach change over the long run.

Unlike permanent beach loss caused by inundation due to sea level rise, which may occur over 100 years, an extremely stormy period has a large impact in a single year. We assume the effects of a major storm season linger for 1 year. The lasting effects of a storm depend on a number of factors including sediment availability and natural recovery. Back-to-back stormy years could also affect beach sand recovery. Thus, our estimates are intended to give an order of magnitude context for the severity of impacts that could result from increased storm intensity. We find that the effects on beach width and beach use of a single extremely stormy year are on the same order as the effects of 100 years of sea level rise.

The effects of waves, especially from storms, on sediment budgets include both increasing volumes of sand and width at some beaches and the loss of sand and width at other beaches. The most extreme changes in beach width exceed those of permanent inundation due to a full meter of sea level rise. Like the effects of permanent beach loss caused by sea level rise, the net economic effect of beach change due to an extremely stormy year is detrimental with a predicted initial, temporary change of annual visits due to an extremely stormy year like that of El Niño equal to −343,446 visitor days and an associated change in total expenditures of −$8.6 million and a change in consumer surplus equal to −$36.7 million (current US$[2000]). Also, like the effects of permanent beach inundation, the effects of erosion events are uneven across beaches.

Also, as in the case of permanent beach loss, there are winners and losers in terms of expenditures. Table 5 demonstrates the range of change in expenditures that could be experienced by the winners and losers in a year with extreme erosion/accretion events. Interestingly, Laguna and Seal beaches, which lose considerable attendance and expenditure with inundation, are expected to be winners due to beach change caused by extremely stormy years. This is because the CEHP model projects a net loss in width for these beaches due to inundation but a net gain due to an extremely stormy year. On the other hand, beaches like Torrance and Redondo, which were expected to lose some visits and expenditure under inundation are worse off after an extremely stormy year because they lose even more width under conditions of extremely stormy wave conditions.

Finally, a breakdown of the change in consumer surplus due to a year-long change in beach width caused by extreme erosion and accretion events reveals variation in impact among the counties in Southern California. Three of the four counties are net losers under beach change scenarios that result from extremely stormy years (even under current sea level). Residents of Los Angeles County experience a large negative impact after an extreme event, losing over $30 million in consumer surplus annually. Orange County is a distant second, with almost $3 million in losses, followed by San Bernardino at about $2 million. However, Riverside County is a net winner, though only by about $350,000. Los Angeles suffers from having many beachgoers that live near beaches that are likely to be badly damaged during an extremely stormy year.

3.3 The costs of mitigating beach loss through nourishment

3.3.1 Estimates of the cost of nourishment

One of the most common ways to combat loss of beach width due to sea level rise is to nourish eroded beaches. There are two major methods: trucking and dredging. Bringing in sand on trucks is cost-effective for small nourishment projects. Dredging, which requires

Table 5 Top five winners and losers with 1 m sea level rise, an extreme storm year

Winners	Difference in annual expenditures (US$[2000], rounded to nearest million)	Losers	Change in expenditure (current US$[2000])
Main Beach Laguna	20 million	Redondo	−25 million
Seal	16 million	Torrance	−21 million
Aliso Creek	1 million	Salt Creek	−19 million
San Onofre South	9 million	Santa Monica	−9 million
Venice	8 million	Doheny	−9 million

Table 6 Estimated costs for hopper dredge nourishment

Mobilization or demobilization	$585,000
Mobilization or demobilization for additional sites	$60,000
Additional cost per cubic meter	$26

expensive equipment has high fixed costs but significant economies of scale. Consequently, our estimates of nourishment costs depend on the amount of erosion. Nourished beaches require periodic maintenance, since waves and currents constantly move sand in the alongshore and cross-shore directions. Sand may also be removed due to persistent background erosion or a storm. Typical re-nourishment intervals under past sea-level conditions range from 2 to 5 years. Between increasing average erosion rates due to sea level rise and the potential that winter times storms will have greater impacts due to increased high tides (Cayan et al. 2008) and longer storm seasons (Peter Bromirski, personal communication), nourishment may need to be undertaken more often in the future to maintain the current quality of Southern California beaches.

Our model captures this effect by providing simple cost estimates for nourishment to counter simple flooding (permanent inundation) due to one meter rise in sea level and the erosional losses that could occur during an extremely stormy year. Recent cost estimates for beach nourishment were estimated for the Los Angeles County Department of Beaches and Harbors (2007).[2] The study developed a general cost structure for nourishment projects in Los Angeles County.

Table 6 indicates that the variable costs of beach nourishment are $26 per cubic meter, including placing sand on the beach and bulldozing. (Fixed) mobilization/demobilization costs were estimated at $585,000 for one project. For additional projects, the mobilization/demobilization costs are much lower, approximately $60,000 for each additional project. Thus, if one is able to schedule a number of projects together, the fixed costs of mobilization and demobilization, as a percentage of the total costs, may be quite low.

Using these cost parameters, the total cost of a nourishment project per beach was estimated for two different scenarios: (1) replacing beach lost due to inundation, and (2) replacing sand lost due to change in beach volume caused by an extremely stormy year at current sea level. The numerical results of our estimates are summarized in Figs. 8 and 9.

The total costs of nourishing all sites to mitigate against conditions in these two scenarios is significant. To mitigate for permanent inundation caused by a rise in sea level of one meter, the total costs of nourishment are estimated to be $436 million, or just over $4 million per year. The cost of mitigating for beach loss from a single stormy year is estimated to be $382 million. Of course, complete renourishment may not take place for all beaches.

While these cost estimates are rudimentary, there is one clear story that emerges from the analysis. The cost of adding sand to beaches to counteract the effects of sea level rise is of a similar magnitude to the costs of renourishing after an extremely stormy year. There is one important difference, however. Inundation takes place over 100 years in our analysis. That means the undiscounted average annual cost of nourishment would be approximately $4

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[2] Data Review and Nourishment Need Assessment, prepared for Los Angeles County Dept of Beaches and Harbors by HPA Inc., September 1997, received directly from Los Angeles County. See Los Angeles County Dept of Beaches and Harbors 2007 for most recent data overview.

a

b
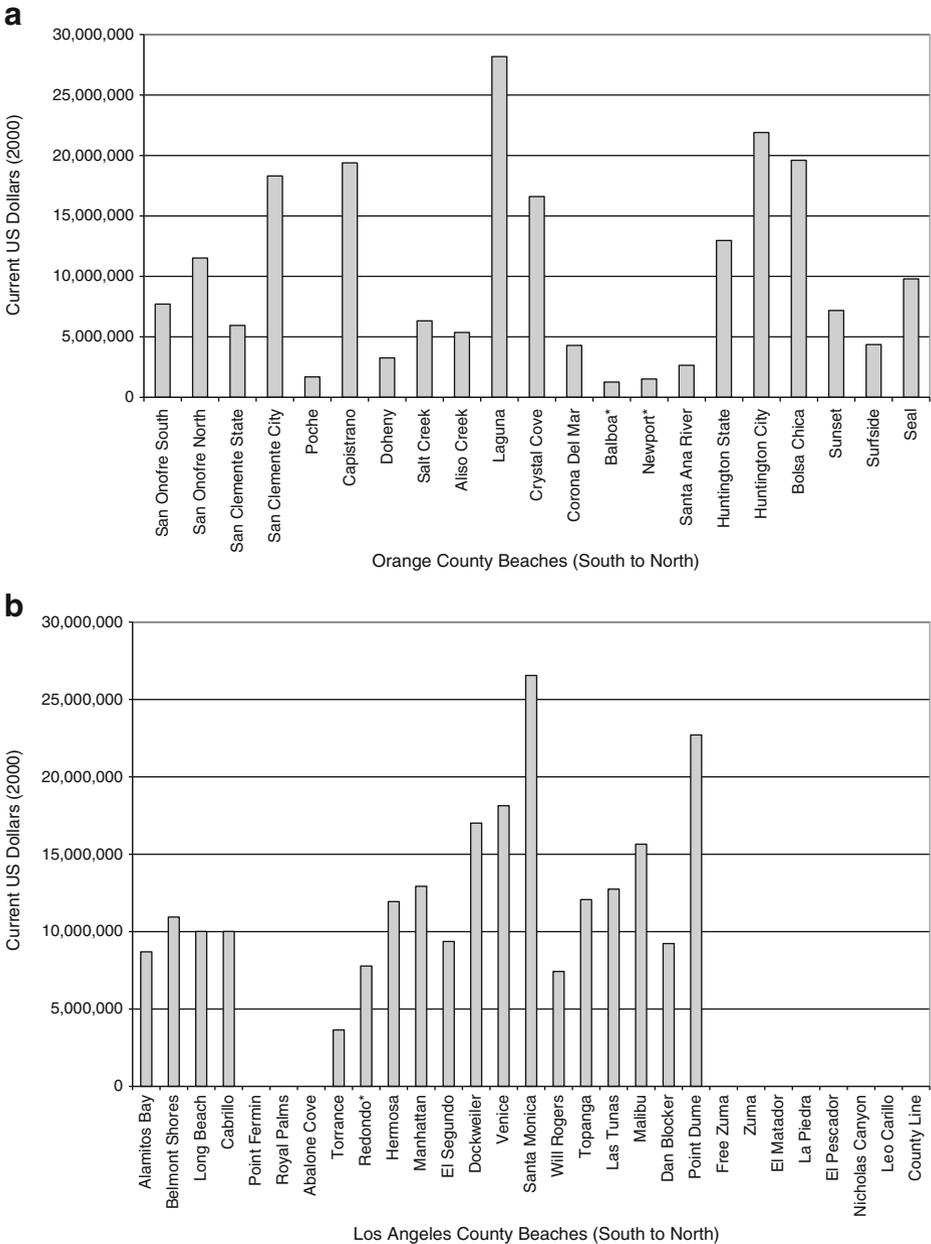
Fig. 8 Estimated costs ($2000) of beach nourishment to mitigate for permanent inundation (1 m sea level rise)

million if sea level rise resulted only in a slow flooding of beaches. This cost is just under one third the estimated loss in consumer surplus due to sea level rise and roughly equal to the average lost expenditures. This suggests that if permanent inundation were the only effect of sea level rise on beaches, then the recreational benefits from nourishment would outweigh the costs. The costs of nourishing for extremely stormy years, however, are many

a

b
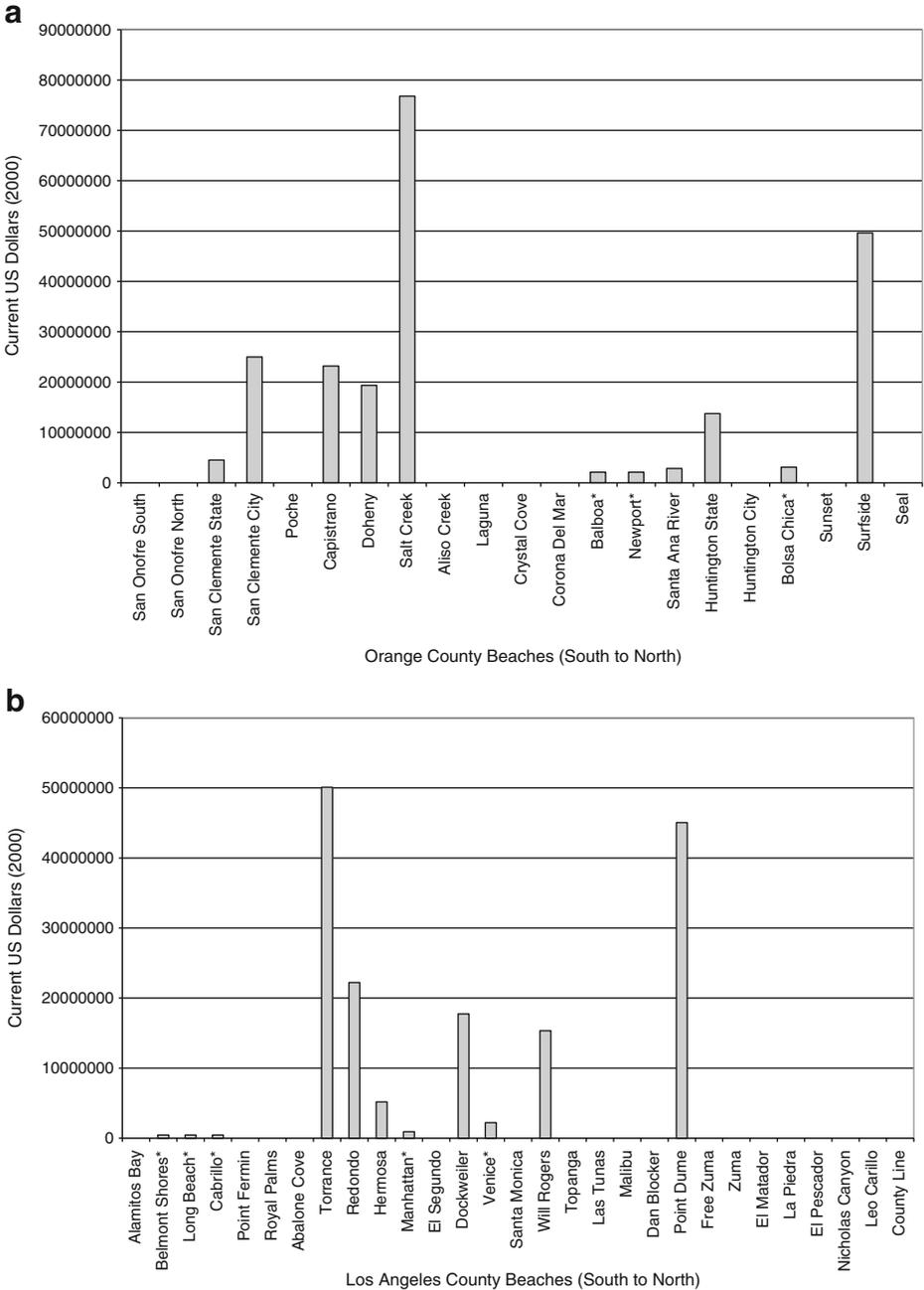
Fig. 9 Estimated costs of beach nourishment (in year 2000 dollars) to mitigate for extremely stormy year. Note: * Indicates trucking is least cost method, otherwise dredging is least cost

times the annual recreational benefit of nourishment. Recreational benefits alone are unlikely to justify the large expenditures that would be required to repeatedly replace sand

Table 7 Annual impacts caused by permanent inundation due to sea level rise of 1 m, US$(2000)

Socio-economic scenario	Total change by residents			Maximum for one beach	
	Annual attendance	Annual expenditures	Annual consumer surplus	Gain in annual expenditures	Loss in annual expenditures
No change	−588,765	−$15 million	−$63 million	$16 million	−$15 million
Low growth	−586,923	−$15 million	−$62 million	$14 million	−$13 million
High growth	−380,223	−$10 million	−$40 million	$7 million	−$8 million

lost by increasingly severe winter storms. For these beaches, the process of natural replenishment is likely to be most cost-effective.

3.4 Limitations of the models and future research

The analysis and estimates above should be considered preliminary. More analysis of the impact of severe winter storms resulting from elevated high tides and the potential impact of lengthening winter storm seasons is necessary. Future research on the probabilistic nature of large storm events could generate useful results as well (Sanstad 2008). Future research on the actual costs of nourishment and whether nourishment is politically feasible would also be helpful. We have made simplifying assumptions about the pace of beach change, sources of sediments, and the costs of transporting sediment. All of these factors need to be considered to make our predictions about potential nourishment costs more accurate. Additional research should also improve our estimates of benefits from nourishment, including buffering against storms and related property damage.[3] As noted above, nourishment costs at many sites run well into the millions of dollars, and the total estimated costs of all dredging runs into the hundreds of millions of dollars. Even with such indirect benefits, direct costs may be prohibitive for many state and local governments.

4 Conclusion

Because there are so many beaches to choose from in Southern California, many of them quite large, beach going is likely to remain an important recreational asset to the area, even in the face of sea level rise. Nevertheless, changes in sea level could reduce the number of beach visits taken in Los Angeles and Orange counties by more than half a million visits annually by 2100. In this analysis, we focus only on day-use beach visits by local residents from Los Angeles, Orange, Riverside, and San Bernardino counties. The effect on tourist visits, which could represent as much as 100 million more visitor days for the region (Pendleton and Kildow 2006), is unknown but likely to follow a similar pattern. More dramatic, however, are the uneven local effects of climate change.

Our analysis shows that even the effects of permanent beach loss due to slow and steady sea level rise would create a substantial loss in economic welfare for the region (between $40 million and almost $63 million annually), with smaller impacts on beach-related expenditures (see Table 7). Perhaps more importantly, though, the effects of the impacts of

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[3] For example, see West et al. (2001) though they find the impacts of SLR on storm damage are likely small (5% or so) these losses could still be large in absolute terms.

Table 8 Summary of annual impacts caused by an extremely stormy year ($2000)

Socio-economic scenario	Total change by residents			Maximum for one beach	
	Annual attendance	Annual expenditures	Annual consumer surplus	Gain in annual expenditures	Loss in annual expenditures
No change	−343,447	−$9 million	−$37 million	$20 million	−$25 million

permanent beach loss due to inundation from sea level rise would be spread unevenly across the region with some beaches gaining attendance and expenditures while other beaches lose visitors and their spending.

If sea level rise proceeds at the slow pace considered in this analysis, then an opportunity to offset the losses in beach width through selective beach nourishment could exist. The costs of nourishment appear to be outweighed by the avoided potential losses in consumer surplus, a measure of beachgoer economic welfare, and avoided lost expenditures. The effects of beach change on tourist visitors are likely to show that the value of mitigating the effects of inundation are even larger than predicted here. Of course, sea level rise is unlikely to proceed slowly and gradually.

The real challenge for understanding and adapting to the effects of sea level rise on beach management could come if winter storms, combined with higher tides, lead to even more erosion than beaches experience currently (Cayan et al. 2008). A single extremely stormy year can have a temporary, but substantial impact on annual beach attendance, spending, and consumer surplus that is similar to the average annual impacts that would result a full meter of sea level rise. We estimate the impacts that might occur during an extremely stormy year like that of the El Niño year of 1982/1983. The impacts of beach loss from these extremely stormy years are of a similar magnitude to those caused by permanent inundation (Table 8), and are likely to be highly uneven across the region. Some beaches may benefit from losses of beach size at nearby beaches and some beaches may actually grow because of future sediment accretion caused by storms. Many other beaches, however, are likely to see sharply lower attendance levels if climate change and sea level rise result in more years with high erosion impacts. As a result, local businesses at highly eroded beaches will feel the loss of beach-related expenditures.

Moving forward, our results make it clear that the real concern for beach going and the beach-related economy have to do with the impacts of wave-driven erosion and accretion. Future research needs to use the framework we provide here to take a more probabilistic approach to understanding the potential impacts that increasing sea levels may have on the erosion impacts of winter storms. Finally, this work shows that whether inundation or wave-driven erosion is the cause of beach change, the effects of climate-driven beach change are extremely uneven in their distribution throughout the region. Estimates of the impact of climate change on beaches must be conducted at a sub-regional level, preferably at the level of individual beaches.

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