WATERSHED ANALYSIS FOR RUNOFF AND EROSION POTENTIAL ON SANTA CATALINA, SANTA CRUZ, AND SANTA ROSA ISLANDS

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ABSTRACT

Digital and remote sensing data combined with spatial analysis tools embedded in a Geographical Information System (GIS) provide a framework for implementing the stratification techniques of watershed analysis required to quantify the effect of landcover on hydrology and geomorphology of island watersheds. The rugged landscapes of Santa Catalina, Santa Cruz, and Santa Rosa islands are subjected to a flashy, often intense precipitation regime, grazing, and fires, such that high runoff and erosion rates are often observed. To examine the relative sensitivity to runoff and erosion across these three largest of the Channel Islands, digital maps of vegetation, geology, soils, precipitation, and topography were combined. GIS tools were used to complete a morphometric analysis of the island watersheds, to characterize the land cover of the sub-watersheds, to interpolate rainfall surfaces based on rainfall gage data and elevation, to estimate storm event runoff, and to calculate potential cell-based sediment erosion. For example, for Santa Cruz Island, a typical winter storm with saturated conditions resulted in an average runoff to rainfall percentage of 52%, with maximum stream discharges averaged over the entire storm event of 6 m^3/s. Erosion potential averaged 8 t/ha, which is comparable to field data reported in the literature.

Keywords: Watershed analysis, runoff, erosion, GIS, remote sensing.

INTRODUCTION

From the early 1800s to the present Santa Catalina, Santa Cruz, and Santa Rosa islands have experienced significant changes in land use patterns. These three islands are the largest of the Channel Islands of south-central California (Figure 1), and each provides a unique environment for studying the long-term response of ecosystems to land use change. Runoff generation and erosion are useful indicators of the impact of land use changes. For example, the pattern of vegetation cover on all three islands has a long history of dramatic changes due to grazing, drought, and fire (Minnich 1980; Hochberg et al. 1980), which has had a significant effect on the pattern of soil erosion for the Channel Islands (Johnson 1980; Butterworth et al. 1993). With recent reductions in the size of the feral and domestic grazing animals all three islands have experienced invasions by exotic species, with the invasion by fennel on Santa Cruz Island well documented by Beatty and Licari (1992). Examination and management of processes within these ecosystems presents a set of scientific challenges that can be partially met through combining field data, modeling, and digital technologies. Digital databases, remote sensing data, and spatial analysis tools embedded in a Geographic Information System (GIS) provide opportunities to archive spatially referenced data that can be analyzed for relations among environmental variables. In particular, with the appropriate

Figure 1. Location map for Santa Catalina, Santa Cruz, and Santa Rosa Islands. Map of California, including county boundaries, and colored map insert after maps available from the Perry-Castaneda Library Map Collection (1998).

digital data sets, GIS software provides a framework for implementing the stratification techniques of watershed analysis required to quantify and interpret the land use, hydrology, and geomorphology of island watersheds. In this report, we describe results from a GIS-based analysis of: 1) watershed morphology, 2) accumulated runoff, and 3) cell-based erosion potential. The mapped patterns of extreme versus moderate runoff and erosion potential exhibited on each island are useful as guides for determining areas that would be more or less sensitive to changes in land use.

STUDY AREA

Climate

The Northern Channel Islands (Santa Cruz (SC) and Santa Rosa (SR) are characterized by a Mediterranean climate with mild, moist winters and moderately warm, generally rainless, hot summers. Average monthly temperatures for the region (Ferren et al. 1990) range from 10°C in January to 18°C in August. Comparable temperatures exist on the islands with higher temperatures prevailing in the summer months in the interior, often exceeding 38°C. The presence of coastal fog is primarily responsible for the narrow seasonal range in temperature. Rates of precipitation are highest at the highest elevations. Minnich (1980) reports that average rainfall in the interior valley of SC is approximately 50 cm with the highest slopes receiving 60 cm or about 15 to 20% more rain than at the lowest elevations. Other observations suggest about 30% more rain at the highest elevations (L. Laughrin, pers. comm. 1997).

The climate for Santa Catalina Island (SCa) has been studied in more detail than that for the Northern Islands and has been summarized in several sources (CNA 1976b; SWRCB 1979; Los Angeles County 1981). Average maximum temperatures range from 17°C in January to 23°C in August (Catalina Visitors Bureau and Chamber of Commerce, pers. comm. 1998). Regional differences in island temperature, precipitation and humidity have been noted (CNA 1976b; SWRCB 1981; W. Bushing unpublished data). Avalon, on the leeward southeast end, tends to experience cooler summers and warmer winters than the Airport-in-the-Sky, located on the island's main ridge. Relative humidity averages 60 to 70% due to the proximity of the ocean. Rainfall occurs primarily from late October through April with reported annual averages varying from about 28 to 36 cm depending on the period used (CNA 1976b; SWRCB 1981). Annual precipitation on the windward coast is lower (20 cm at Little Harbor) than that on the leeward coast (35 cm near Avalon) (SWRCB 1979; Minnich 1980), perhaps in response to the orographic effect of the island's main ridge.

Geology and Topography

Santa Cruz and Santa Rosa Islands, are 249 km² and 214 km² in size and rise steeply to 750 m and 475 m (Power 1980), respectively. The Northern Channel Islands are a structural element of the Western Traverse Ranges Province and are considered an extension of the Santa Monica Mountains to the south of the study area (Dibblee 1982; Patterson 1979). The Northern Channel Islands are a mix of volcanic and volcaniclastic sediments of Miocene age and pre-Cretaceous crystalline basement which are typically overlain by marine and non-marine sedimentary and volcaniclastic Tertiary deposits (Dibblee 1982; Patterson 1979; Jones and Grice 1993). Each island has a major fault system running through it, with the Santa Cruz Island fault forming a valley and the Santa Rosa Island fault forming a ridge (Dibblee 1982).

Santa Catalina is 194 km² (Minnich 1980), 4 km long, and varies in width from 0.7 km at the Isthmus to 12.8 km (Long Point to China Point). The island is the emergent portion of an elevated fault block that trends from the northwest to the southeast (SWRCB 1981), paralleling the ridge and basin topography of the Borderland (Rowland 1984). A well-defined main ridge with an elevation of 400 to 500 m extends from end-to-end, essentially unbroken except at the Isthmus. This effectively divides the island into windward (southwest-facing) and leeward (northeast-facing) slopes. The maximum elevation of 639 m on Mount Orizaba, at a closest distance of 4,800 m from the windward side shoreline, results in a 13% grade. In contrast, most of the central ridgeline is much closer (1,400 to 3,100 m) to the leeward coast than the windward coast, creating steeper slopes on that side. The island's rugged topography strongly influences its coastal configuration which consists of steep slopes and precipitous cliffs interrupted by canyons (Pipkin et al. 1973 in CNA 1976a, 1976b; Los Angeles County 1981). The steepest coastal cliffs (427 m or 1,400 ft) are in the region of the Palisades east of Silver Canyon on the southeastern windward end of the island (Bailey 1941).

Water and Sediment Transport

On Santa Cruz Island, Brumbaugh (1980) interpreted several stratigraphic sections of channel deposits that show a fine alluvium capped with coarse, poorly-sorted alluvium, as evidence for a change in the sediment transport processes during historic time. Intensity of grazing on Santa Cruz Island has fluctuated for the past two centuries with a resulting loss in vegetation cover. "The slopes, overgrazed and made barren by sheep, may have become dominated by rilling and mass wasting…" (Brumbaugh 1980:149) which has produced this coarser surface alluvium. Recent reductions in the sheep population have resulted in some recovery of vegetation (Brumbaugh 1980; Beatty and Licari 1992), but no study has been completed to determine if there has been reduction in sediment erosion. Renwick (1982) documented several types of mass movements on Santa Cruz Island as the result of intense rainfall during the winter of 1977 to 1978. The factors controlling the extent and type of mass wasting included lithology, topography, soil type, and vegetation cover. In particular, the permeability of soils, as interpreted from soil texture data, seemed to be the most important for determining the morphology and frequency of the landslides. Recently collected field data on landslides resulting from the 1997-1998 El Niño storms show that three major types of mass wasting occurred: shallow soil slumps, slope-parallel slips, and deep-seated slides, with the highest occurrence in the form of soil slumps on slopes between 25 and 40° (Knutsen et al. 1998).

In an effort to examine the impact of land use change on erosion on Santa Rosa Island, Cole and Liu (1994) described the Holocene conditions of deposition in a small estuary on Santa Rosa Island. The rates of deposition in this estuary, which has a drainage basin area of approximately 480 ha, ranged from 0.07 mm/yr prior to 1800 AD to 24 mm/yr during the most intensive grazing period between 1874 and 1920 AD. These deposition rates yield relatively low rates of erosion, 0.06 t/ha. However, Cole and Liu (1994) only reported on rates of deposition in the estuary and did not report transport measurements for the entire watershed.

Information is scarce regarding runoff and erosion potential on SCa. Fortunately water quality problems, as identified by the state (SWRCB 1979, 1981) are minimal. There are no point sources of industrial waste discharged, municipal wastes are handled by sewage treatment facilities and no agriculture or logging activities occur on lands that drain into the nearshore environment.

MATERIALS AND METHODS

Hydrologic Data

This study was designed to provide maps indicating the patterns of sensitivity to runoff and erosion of the three largest Channel Islands. To illustrate these patterns we chose to use a moderate storm size for generating runoff and erosion. To choose the appropriate storm we analyzed the precipitation records available for each island. The rainfall records for SC and SR are not complete enough to produce a quantitative analysis of the frequency of recurrence of different storms. In addition, there are not enough rainfall stations (2 on SC, none on SR) with sufficiently long records to be able to analyze in detail the effects of topography on the amount of precipitation, other than the observations reported by Minnich (1980) and L. Laughrin (pers. comm. 1997). SCa has a slightly better set of records for rainfall. The Avalon, Two Harbors, Middle Ranch, and Airport-in-the-Sky rainfall records were used to compute the orographic influence on Catalina rainfall. The result of this analysis, based on ten years of record, is that for average annual rainfall:

$$PPT = 0.0036 \text{ (elevation)} + 12.405 \text{ (inches)}. \quad (1)$$

PPT is the predicted rainfall in inches, and the relationship has an $r^2=0.9522$ for four data points. A Log Pearson Type II frequency analysis (James and Lee 1971) for storm recurrence was completed for the Avalon rainfall record using the annual maximum 24-hour total.

Remote Sensing Data and Methods

Remote sensing data were used to generate a landcover map for both SC and SCa. A cluster analysis in ARC/Info/Grid (AIG) of a October 20, 1993, Landsat Thematic Mapper image and a March 12, 1990, SPOT (Systéme Probatoire l'Observation de la Terre) image was completed. As reported by Mertes et al. (1998) for SC the cluster analysis yielded seven clusters, two of which were in the ocean. Each cluster was named to a broad community type, e.g., dense woodland, based on comparisons to aerial photographs and a vegetation map provided by Minnich (1980). The 1993 landcover map has all of the "vegetation" categories listed by Jones and Grice (1993) in their Table 2, including grass, oaks, coastal sage, chaparral, pines, and bare. Chaparral and pines were combined into a dense woodland group in the current study. A more complete analysis of this image, including an accuracy assessment based on field sites, is described in this volume by Cobb and Mertes (1999).

The remote sensing analysis of SCa was similar to the analysis for SC. To augment the three SPOT bands and to reduce the effect of topographic lighting, an image of the normalized difference vegetation index (infrared-red/infrared + red; Jensen 1996) was included in the cluster analysis. Twelve vegetation classes were chosen for the cluster classification for SCa. These classes include two grass classes, two oak classes, three barren classes, two sage classes, one cultivated vegetation class, one grass/sage class, and water. Test sites for accuracy assessment were based on field observations in May, 1998, the Minnich (1980) map, and the Catalina Conservancy digital vegetation map (W. Bushing, unpublished data; Thorne 1967).

Other Digital Data

United States Geological Survey digital elevation (30-m spatial resolution) and digital line graph data at 1:24,000 formed the basis for the topographic and morphometric analysis of the Northern Channel Islands. Geologic data for SR and SC were digitized from 1:250,000 scale maps (Weaver et al. 1969). Digitized vegetation maps of Santa Rosa Island (C. Schwemm, unpublished data) were based on maps produced by Clark et al. (1990). The digital elevation data for Catalina were digitized from USGS topographic maps and the grid is calculated with a 20-m spatial resolution (W. Bushing and Catalina Conservancy, unpublished data). The soils map for SCa used in this study was based on data assembled by the Center for Natural Areas (1976a), based on Soil Conservation Service Mapping from 1955 (W. Bushing, unpublished data).

GIS Methods

Arc Macro Language programs (AMLs) in AIG were written and are described in detail by Mertes et al. (1998). These programs were used to complete a morphometric analysis of the three islands, to interpolate rainfall surfaces based on elevation, to characterize sub-watersheds, to estimate storm event runoff, and to calculate potential cell-based sediment erosion. The morphometric analysis is based on cell-based modeling techniques described for AIG (Maidment 1995; Mertes et al. 1998), and involves dividing the island watersheds into progressively smaller sub-watershed units. The hierarchy of the watersheds and streams is numbered according to Strahler (1964) such that the 1st-order sub-watersheds have on average the smallest area and shortest streams. Watershed area and stream length are expected to increase with order using this methodology.

This study was designed to provide simulated runoff and erosion in response to a typical winter storm over the three islands. To make the results comparable, a single storm was chosen which is the four-day (three days on SCa) storm leading up to February 9, 1994. Based on the Log Pearson frequency analysis for SCa this storm has a recurrence interval of approximately 3 years. For SR and SC the recurrence interval is probably less than 10 years. Because rainfall data for the islands are only available as point data, it was necessary to generate a rainfall surface of total precipitation for this storm. The rainfall surface that was used for SR and SC was generated based on rainfall data from SC. This storm sequence generated 13 cm of rain at the low elevation rain gage on SC. Using the 30% increase in rainfall at the highest elevations suggested by L. Laughrin, a rainfall surface was linearly interpolated for both islands starting with 13 cm at the lowest island elevations and gradually increasing to 16.5 cm at 800 m for SC and 15.2 cm at 475 m for SR. This storm was not as intense on SCa, where only 5 cm of rain fell at Avalon. Equation 1 was used to compute the rainfall surface as a function of elevation for Sca.

The runoff model requires landcover and soil inputs for characterizing soil hydrology (4 categories of infiltration potential from high to low, e.g., see Table 10-4 Dunne and Leopold 1978) and influence of the landcover on hydrology, (see Table 10-3 and Table 10-5 in Dunne and Leopold 1978). A runoff curve is assigned to each cell, a rainfall surface is applied, and runoff generated for each cell. The total runoff into each cell is then calculated using the **flow accumulation** Grid function and the weighted runoff grid. The AML code for surface erosion is based on the Universal Soil Loss Equation as outlined by Dunne and Leopold (1978) where A=RKLSCP. A is soil loss in tonnes per hectare (t/ha), R is the rainfall erosivity index, K is the soil erodibility index, L is the hillslope-length factor, S is the hillslope-gradient factor, C is the cropping-management factor, and P is the erosion-control practice factor (Dunne and Leopold 1978).

For the soil erosion analysis map algebra techniques were used to assemble all of the parameters except the P factor for erosion-control practice, which was assigned an intermediate value (Table 15-5, Dunne and Leopold 1978, p. 530) of 0.5 for all cells. Assignment of values for the other parameters was based on soil, landcover/vegetation, and rainfall data. In order to assign hydrological properties and K values, soil properties had to be examined. The soil properties for Santa Cruz Island were based on research and digital data sets described by Jones and Grice (1993) and Butterworth et al. (1993). The soil properties for SR were determined by comparing the geology to SC and assigning the same values as had been assigned to the SC soils for the same geology (see Mertes et al. 1998 for details). Values for SCa were based on the values assigned by the Soil Conservation Service that were supplied with the digital data. The K values (e.g., see Figure 15-17 Dunne and Leopold 1978) ranged from 0.3 to 0.45 for all three islands. The hydrological properties varied across the four available categories for high to low infiltration potential.

RESULTS

To evaluate the sensitivity of these island landscapes to land use change an analysis of the watershed morphometry, runoff potential, and erosion potential was completed. Results of the morphometric analysis are shown in Figure 2 where a comparison of the drainage basin structure for each island for each order is presented. The statistics presented for each of the islands suggest that the islands are morphometrically similar for the first, second, and third order watersheds. At the fourth order, differences among the islands begin to show. The average stream length and watershed area for the fourth order watersheds on SR are larger than the other two islands, although the differences are not statistically significant due to high variance and low number of samples. The largest watershed on all three islands is a sixth-order watershed on SCa with a drainage area of 37 km^2.

Results for the cell-based runoff and erosion potential simulations are shown in Figures 3 and 4. The average rainfall-runoff percentage for SC is 52% with a standard deviation of 13%, for SR it is 48% with a standard deviation of 10%, and for SCa it is 29% with a standard deviation of 14%. Figure 4 shows that extreme runoff (>60%) was experienced by 23% of SC, 5% of SR, and <1% of SCa. On the other hand, 70% of SCa experienced a low runoff conversion (<20%) compared to 21% of SC and 8% of SR.

The cell-based runoff totals can be combined to produce an indication of the total runoff in centimeters experienced along each drainage network. Mertes et al. (see Figure 5 in 1998) reports these results for SC and SR. The maximum total runoff accumulated for the entire storm for a single channel at its mouth for SC is 2,220,600 m^3 (average of 6 m^3/s for the four-day storm event), for SR is 1,188,800 m^3 (average of 3 m^3/s for the four-day storm event), and for SCa is 1,100,600 m^3 (average of 4 m^3/s for the three-day storm event).

The pattern of erosion for each cell is shown in Figure 3, with summary statistics shown in Figure 4. As expected, the largest erosion rates (>100 t/ha; shown as red) are along the high, steep ridges of SC. The rates of erosion potential are lower in general for SCa with (96%) experiencing low rates (0 to 20 t/ha) and no areas experiencing extreme erosion (>150 t/ha). In contrast, both SC and SR have >45% of their area experiencing high (20 to 150 t/ha) rates of erosion potential. Extreme rates of erosion were simulated for 4% of SC and 2% of SR.

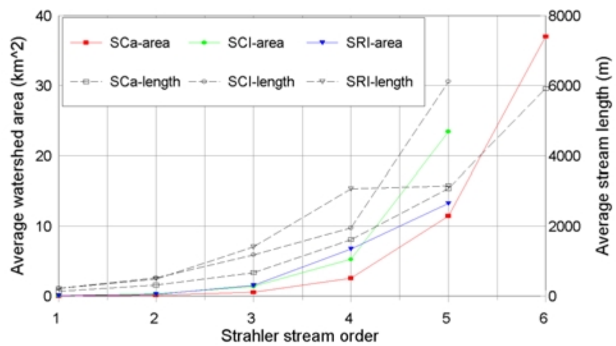

Figure 2. Morphometric characterization of Santa Catalina (SCa), Santa Cruz (SC), and Santa Rosa Islands (SR). The numbers plotted for each watershed and stream order are average watershed area and average stream length, respectively. Characterization based on a minimum watershed size of 1 km².

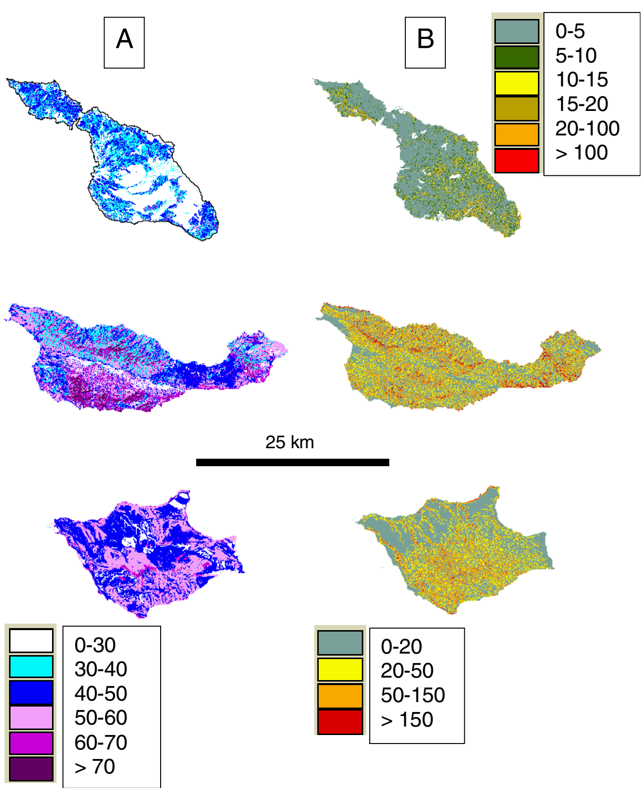

Figure 3. A) Percentage of rainfall converted to runoff for storm ending on February 9, 1994 for Santa Catalina, Santa Cruz, and Santa Rosa Islands (top to bottom). For all three islands the intensity of the storm was moderate with a recurrence interval of less than 10 years. B) Potential erosion for the same storm in metric tons per hectare (t/ha) for Santa Catalina, Santa Cruz, and Santa Rosa Islands. The legend for Santa Catalina is different, because the range of values was not as large.

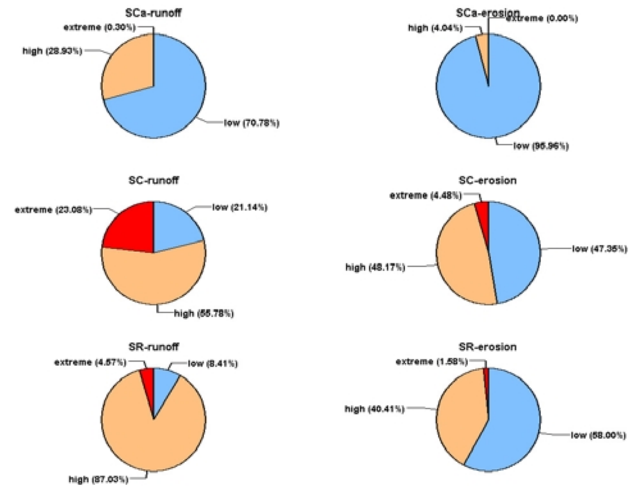

Figure 4. Sensitivity to runoff and erosion for each island as a percentage of total island area. SCa = Santa Catalina, SC = Santa Cruz, and SR = Santa Rosa Islands (top to bottom). Excess runoff = >60%, high runoff = 20 to 60%, low runoff = <20%, extreme erosion = > 150 t/ha, high erosion = 20 to 150 t/ha, and low erosion = < 20 t/ha.

DISCUSSION

In order to effectively manage natural landscapes, insight into the response of the ecosystem to land use change is needed. Changes in runoff and erosion are often some of the first indicators of the impact of land use change. Therefore, it is useful to prepare base line maps that show the sensitivity of the landscape to runoff and erosion. Once these have been assembled, scenarios for land use change can be simulated to demonstrate long-term potential impacts. Given the 200-year history of dramatic shifts in land use on the Channel Islands, from natural to grazed to restoration, it is of interest to analyze the current conditions of runoff and erosion potential, thus providing a reference point for future management decisions.

The techniques employed in this study are primarily based on computer simulations of the potential for runoff and erosion. Therefore, the mapped results are not resolved to the field plot scale, whereby one would expect that a field measurement would exactly match the simulated conditions. Instead, these results are useful as indicators of the relative sensitivity of different areas of the landscape to runoff and erosion. With respect to runoff, the methods described here do not characterize a detailed water balance, but instead rely on the Soil Conservation Service methods for determining the relationships between soil type, landcover, and hydrology. With respect to erosion, the methods used in this study do not include erosion due to mass wasting (see for example, Dietrich et al. 1993). In addition, the USLE methods were originally developed for field plots in gently sloping cropland (Wischmeier 1976). Therefore, application to these steep, natural terrains should be limited (Wischmeier 1976; Wilson and Gallant 1996) to general characterization of the rates of erosion into categories such as extreme, high, and low as shown in Figure 4.

With these limitations in mind, it is of interest to examine the spatial patterns of the three largest Channel Islands with respect to 1) watershed morphometry, 2) runoff potential and 3) erosion potential. Although the differences in the morphometric structure of the islands (Figure 2) are not statistically significant due to the high variance and low number of samples in the data, the trend reflects the physiographic characteristics of the islands. The topography of Santa Rosa Island is dominated by a central highland formed along the Santa Rosa Island fault (Dibblee 1982) from which all of the major drainage systems radiate and drain into the ocean. The result of this island-scale structure is that the fourth-order drainage basins of Santa Rosa Island have relatively long lengths and the basins extend from the highest peaks to the ocean boundary. In contrast, Santa Cruz Island is cut in half by the Santa Cruz Island fault, which has produced a large interior valley flanked by ridges to the north and south (Dibblee 1982). Therefore, many of the fourth-order drainage basins of Santa Cruz Island are confined to gentler parts of the landscape as the channels cross the low gradient central valley. Santa Catalina Island is intermediate between the other two, in that the isthmus prevents drainage from one end of the island to the other, thus acting similarly to the main valley of SC. Yet, like SR, the central highlands of SCa result in a radial drainage system for the two halves of the island. In addition, on SCa there is an asymmetry to the watershed structure with longer stream systems on the windward side and shorter, steeper systems on the leeward side.

With an understanding of the morphometry, the next step is to compare the runoff for each island. The percentage of rainfall converted to runoff across each island varies as a function of soil type and vegetation/land cover. This parameter was chosen for the maps, because it will vary less with different storms than the actual amount of runoff per grid cell. The patterns for SC and SR (Figure 3A) show that the highest rates of runoff are along the steepest ridges often in places of exposed bedrock or barren soils. These extreme conditions of runoff do not show up on SCa, where the south central portion of the island experiences a 0 to 30% runoff conversion. The steeper, more exposed slopes of the northwest part of the island show higher rates of rainfall to runoff conversion, with a maximum rate of 70%. Based on these results it appears that the conversion of rainfall to runoff is less efficient on SCa and the most efficient on SC. Nevertheless, the average rates are relatively high, ranging from 29 to 52%, when compared to rates for other natural landscapes (e.g., Dunne and Leopold 1978) that are less steep, have deeper soils, and experience lower rainfall intensities. As each island recovers from grazing pressures it is not clear whether the changes in land cover (e.g., Beatty and Licari 1992) will result in a reduction in the production of runoff to values more akin to these other types of landscapes. It is probable that even the restored natural conditions would continue to produce high rates of runoff.

The mean rates of erosion potential of 8 t/ha (SC), 6 t/ha (SR), and 4 t/ha compare well to values ranging from 1.2 to 11 t/ha listed by Dunne and Leopold (see Table 15-1 in 1978) for southern California woodland and rangeland (originally reported by Krammes 1960). Ninety-six percent of SCa has rates <20 t/ha, which is essentially in the range of these literature values. The rates are most extreme on SC where more than half of the island experiences erosion rates > 20 t/ha.

The erosion rates reported here indicate the rate of transfer of sediment from hillslopes to the channel systems. The processes responsible for this erosion could induce the rills and surface erosion reported by Brumbaugh (1980). The fact that the reported rates are based on the conditions from 1990 (SCa), 1993 (SC), and the early 1990s (SR), also means that they include the effects of 200 years of grazing through the landcover. Nevertheless, it is difficult to put these rates into the context of reports by Brumbaugh (1980), where he reported on the effects of significant erosion across island watersheds and concluded that the long term impacts of grazing had been to accelerate erosion, because no rates were given. Similarly, Cole and Liu (1994) showed shifts in sedimentation rates that they associated with accelerated erosion and sediment transport due to increased human activities on SR, but were not able to calculate the rates of sediment production. Rice (1982), Scott and Williams (1978), Taylor (1983), and Milliman and Syvitski (1992) report that the steep coastal drainage basins of the mainland of the south-central coast of California have some of the highest denudation rates (millimeters per year) measured in the world. Although the island watersheds are not as large as the mainland watersheds, the source of sediment is hillslope erosion which is probably comparable between the islands and mainland.

The runoff and erosion results reported here essentially simulate conditions on the three largest Channel Islands for the early 1990s. Since then each island has been experiencing a different recovery and restoration pattern which is not included in this study. An update of these results with new maps of landcover and vegetation would provide a means of examining the effect of a decade of change, especially if there has been significant conversion from barren or grassland to more shrub-dominated landcover. However, it is reasonable to predict that the natural potential for runoff and erosion in these rugged island watersheds will remain high relative to other landscapes even if there is full restoration of native communities.

CONCLUSIONS

GIS-based analyses were completed for the three largest Channel Islands, Santa Catalina, Santa Cruz, and Santa Rosa, in order to evaluate the sensitivity of the island watersheds to land use change. These analyses included 1) watershed morphometry, 2) runoff potential, and 3) erosion potential. The watershed morphometry, i.e., stream length and watershed area, of the three islands is similar up to the third order watersheds. The fourth-order watersheds of SR are larger and longer than the same order for the other two islands. This reflects the presence of a ridge on SR from which all of the major drainages radiate. The ridges and valleys of SC and SCa are such that the drainage configurations are not as symmetric and therefore, at the fourth order not as extensive as on SR. The largest watershed is a sixth-order watershed on SCa with a drainage basin area of 37 km^2.

The simulated rates of runoff and erosion reflect land cover from the early 1990s and are based on a storm that ended on February 9, 1994. The simulated mean rates of conversion of rainfall to runoff (percent runoff) are generally high because of the steep terrain and shallow soils, ranging from 52% for SC to 48% for SR to 29% for SCa. Runoff conversion on SCa is less than 40% for over 70% of the island. Conversion was more efficient for SC and SR where over 50% of each of the islands experienced a 40 to 60% runoff percent. The mean erosion rates for all three islands were within the range (1 to 11 t/ha) reported in the literature for similar landscapes, but large portions of SC (52%) and SR (42%) experienced rates > 20 t/ha. SCa experienced relatively lower rates of erosion potential (<20 t/ha for 96% of the island), with a mean of 4 t/ha.

The potential rates of runoff and erosion in the rugged watersheds of the Channel Islands are relatively higher than those for most other landscapes because of the steepness of the terrain, the shallow, erodible soils, intense rainfall, and sparse vegetation cover. The impacts of grazing are reflected in the modern patterns of land cover, vegetation type, and surface properties of the soils. The rates reported here are based on data for land cover from the early 1990s and soil properties determined in the last several decades. All of these data sets represent conditions that have resulted from previous land uses, most notably grazing. As each island recovers from 200 years of grazing, it may be that the rates of runoff and erosion will decrease. However, even if fully recovered from human impacts, the natural physiography and climate will always produce some of the highest rates of runoff and erosion known for any landscape.

ACKNOWLEDGMENTS

This research was supported by the Catalina Conservancy and the UCSB Instructional Development Program. Funding for development of the data sets was provided by the Channel Islands National Park, Santa Cruz Island Reserve, University of California Natural Reserve System, NOAA Channel Islands National Marine Sanctuary, and the State of California Office of Oil Spill Prevention. C. Schwemm (Channel Islands National Park) provided the digital vegetation map of Santa Rosa Island.

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