

Historic Evolution of a Marsh Island: Bloodsworth Island, Maryland

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ABSTRACT



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High rates of relative sea-level rise in the Chesapeake Bay of about 0.3 m/century has caused rapid land loss of the Bay islands. This study is the first quantitative analysis of both perimeter and interior land loss for one of the large marsh islands—Bloodsworth Island. A geographical information system (GIS) was used for the analysis at a resolution of about 16 meters.

From 1849 to 1992, the area of Bloodsworth Island declined by 579 ha, or 26% of the land area in 1849. The land loss can be divided into four geomorphic types: perimeter land loss, channel widening, channel ponding, and non-channel ponding. Perimeter land loss is largest at 3.0 ha/yr from 1942 to 1992, but the three interior land loss types are also significant, totalling 1.6 ha/yr from 1942 to 1992. Channel ponding and widening were responsible for nearly all interior land loss prior to 1942. The initial formation of non-channel ponds is attributed to a short-term acceleration in sea-level rise (to 7 mm/yr from 1930 to 1948). Subsequently, non-channel ponding has been significant, particularly in the southeastern quadrant of the island. Compared to the mainland marshes, interior land loss has occurred at much slower rates; this is probably due to the low thickness of the marsh deposits on Bloodsworth. To date, bombing appears to have only had a secondary impact on land loss at the scale of this study.

In the future, the island appears increasingly vulnerable to interior break-up, particularly given another short-term acceleration of sea-level rise.

ADDITIONAL INDEX WORDS: *Sea-level rise, Chesapeake Bay, coastal wetlands, inundation, coastal erosion, GIS, ponding.*

INTRODUCTION

The Chesapeake Bay is the largest estuary in the United States. It formed over the past 10,000 years as the rising sea level progressively submerged the valley of the Susquehanna River. The Bay is approximately 300 km long and ranges from 5 to 56 km wide. The western coast of the Bay is characterized by high relief, whereas the eastern coast is characterized by lower elevations, including extensive areas of coastal wetlands and a number of low islands, generally comprised of wetlands (WRAY, 1992; LEATHERMAN *et al.*, 1993).

The Chesapeake Bay is experiencing rapid rates of relative sea-level rise of about 3 mm/yr (LYLES *et al.*, 1988). At the same time, the coastal wetlands have experienced rapid rates of land loss. The best documented cases are Blackwater National Wildlife Refuge (STEVENSON *et al.*, 1985) and on the Nanticoke River (KEARNEY *et al.*, 1988). These losses can be attributed to an accretion

deficit: relative sea-level rise is faster than vertical accretion of the marshes which are ultimately inundated (STEVENSON *et al.*, 1986). Geomorphologically, the land loss is dominated by interior land loss processes, including the formation of interior ponds.

The islands are also experiencing rapid land loss and habitat change due to relative sea-level rise. WRAY (1992) and WRAY *et al.* (*in preparation*) examined perimeter land loss of many of the islands in the Bay. Unlike many of the coastal wetlands on the mainland, the islands are exposed to significant wave activity and have very limited or no protective beaches. Therefore, land loss of marsh-dominated islands may involve three major groups of processes: (1) perimeter erosion (by wave action), (2) channel formation and enlargement, and (3) interior pond formation. Erosion and/or submergence of the islands and coastal wetlands by sea-level rise will affect the entire Bay ecosystem (LEATHERMAN *et al.*, 1993). The islands provide important wildlife habitat, and its

importance will likely increase as human development of the mainland shore continues.

This paper is the first quantitative analysis of both perimeter and interior land loss for one of the large marsh islands in the Chesapeake Bay. It presents the geomorphic and spatial patterns and rates of land loss on Bloodsworth Island from 1849 to 1992. It also forms part of a study which will create a comprehensive data base of Bloodsworth Island in a geographic information system (GIS) for improved habitat and wildlife management.

Bloodsworth Island

Bloodsworth Island (Figure 1) is the northernmost of a 40 km chain of marsh islands that terminates with Tangiers Island. It is exposed to wave action on its entire perimeter, with the largest fetch (32 km) on the northern and western shores which face the open Bay. The tidal range is approximately 0.4 m and the majority of the island is at or near sea level, making most of it intraversable at high tide. The salinity is 15 to 17 ppt which is typical for this part of the Bay and characterizes Bloodsworth Island as a brackish marsh. Presently, there is no fresh water on the island. However, in the 1960's scattered patches of fresh water "swamps" were noted among the predominant tidal marsh vegetation (WILKE *et al.*, 1980).

As with most of the other islands in the Bay (cf. KEARNEY and STEVENSON, 1991; LEATHERMAN, 1992), Bloodsworth Island was formerly inhabited by human populations. Abandonment by year-round residents occurred by 1920. Anecdotal evidence suggest that this was prompted by salt-water intrusion into the groundwater. Similar accounts suggest that other changes have occurred because of the loss of freshwater, including a decline in the diversity of wetland species and the size of waterfowl and other wildlife populations. A number of small upland ridges formerly existed, with a general north-south axis. These ridges were characterized by stands of loblolly pine (*Pinus taeda*) and, prior to abandonment, were often sites of agriculture plots (WILKE, *et al.*, 1980). The extent to which agriculture resulted in deforestation of the upland areas is not documented. The last loblolly pines (*Pinus taeda*) died during the 1960's, seemingly due to increased waterlogging and/or saltwater intrusion.

Presently, Bloodsworth Island occupies approximately 1,700 ha; almost entirely brackish

saltmarsh, of the submerged upland marsh type (STEVENSON *et al.*, 1986). There is one remaining ridge (less than 12 ha) with large bushes and a few locust trees (*Rabinia*) which are in poor health. In 1980, 83.8% of the island was vegetated by black needle rush (*Juncus roemerianus*) (Table 1). There is a thin veneer of sand beach along much of the western shore, but this affords little protection to the underlying substrate. The marsh deposits are thin (one meter or less) as shown by shallow coring (WILKE *et al.*, 1980) and exposed edges of the island. Beneath the marsh deposits is a silty clay loam substrate which constituted upland prior to inundation and conversion of the island to marsh. The low thickness of the marsh suggests that inundation occurred recently in geological terms, probably during the last millenia, but this has not been dated.

Bloodsworth Island was purchased by the U.S. Navy in 1948 and is used as a bombing and shelling range. Therefore, the contribution to wetland loss of the numerous impact ponds formed during practice bombing needs to be considered, in addition to the effects of erosion and inundation.

Sea Level Rise in the Chesapeake Bay

KEARNEY and STEVENSON (1991) have presented evidence based on the rate of land loss on the Bay Islands, and the vertical accretion of marshes, that sea-level rise in the Bay accelerated around 1850. Therefore the coastal wetlands in the Bay may have been responding to some of the highest rates of relative sea-level rise of the last five millenia.

The longest mean sea level record in the Chesapeake Bay is from Baltimore (LYLES *et al.*, 1988), about 120 km north of Bloodsworth Island. This gauge indicates a significant rise in sea level of 3.1 mm/yr from 1903 to 1992 (Figure 2). This rate is generally consistent with recent rates of global sea-level rise if post-glacial rebound is considered (DOUGLAS, 1991). There is considerable inter-annual variability typical of sea-level records, so the data are smoothed with a five-year running mean. This shows a generally rising trend, although there are periods as long as a decade of sea-level fall, most particularly in the 1920's and 1970's. Periods of rapid rise are also apparent. This was particularly true of the period from 1930 to 1948, when based on the running mean sea level rose about 0.13 meters. This was equivalent to a rate of over 7 mm/yr. These fluctuations in mean sea level are attributed, in part, to temperature-controlled

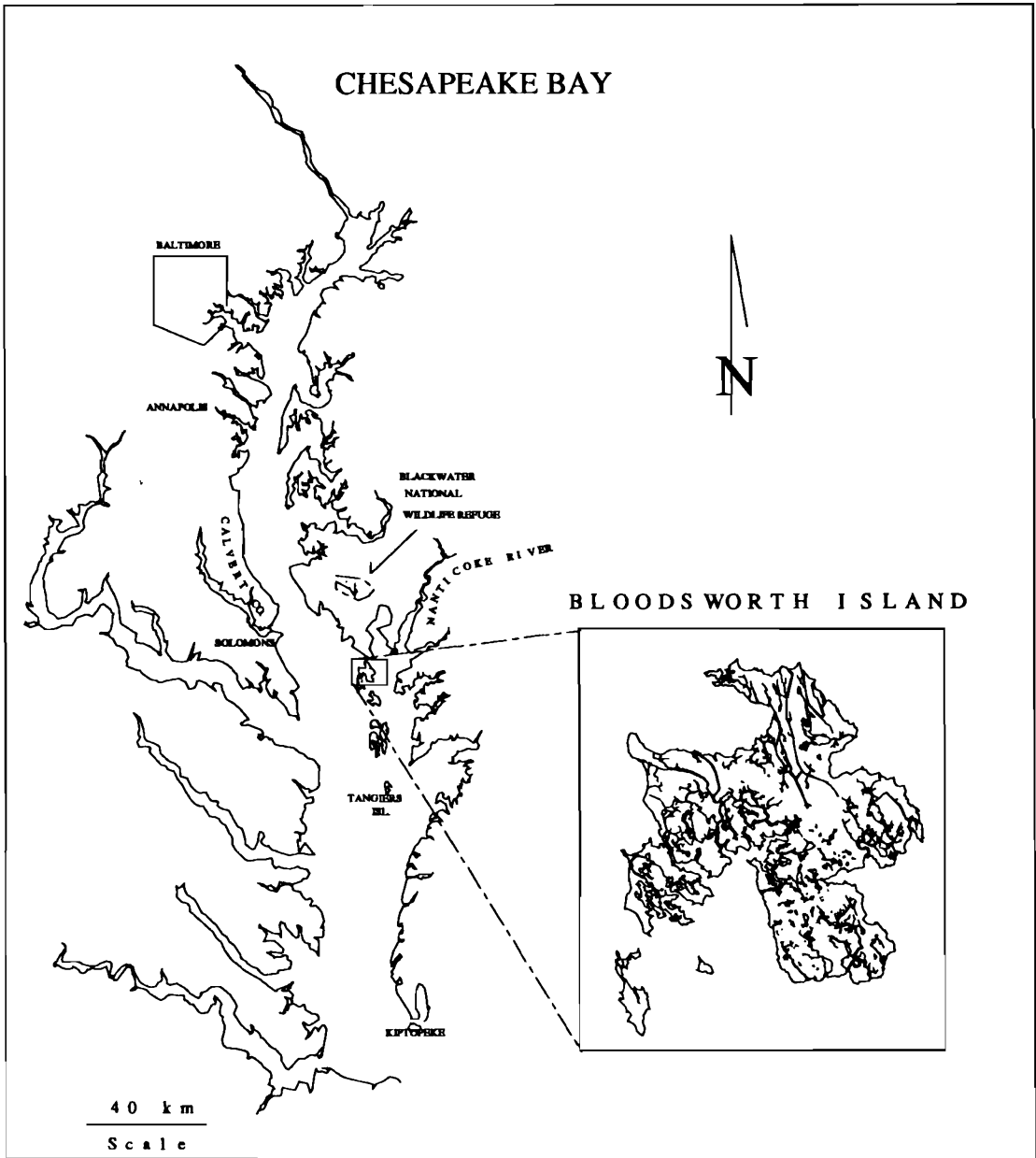


Figure 1. Location map.

changes in density of the water entering the Bay from the ocean (DOUGLAS, *personal communication*, 1994).

Another sea-level records of shorter duration are available from Annapolis, Md., Solomons, Md., and Kiptopeke, Va. These show a rise in sea level

that is 8, 19 and 14% faster than at Baltimore, respectively, when comparing records of equal length (WRAY, 1992). In the last decade, the record shows that mean sea level is dropping at Baltimore, but is remaining constant at Solomons (DOUGLAS, *personal communication*, 1994).

Table 1. Vegetation cover on Bloodsworth Island in 1980 (after WILKE et al., 1980).

Type of Vegetation	Land Cover (%)
Black Needle Rush (<i>Juncus roemerianus</i>)	83.8
Saltmeadow Cordgrass (<i>Spartina patens</i>)	9.4
Saltmarsh Cordgrass (<i>Spartina alterniflora</i>)	4.3
Marsh-elder/Groundsel-tree (<i>Iva frutesces/Baccharus halimifolia</i>)	2.5

Therefore, the rate of relative sea-level rise at Bloodsworth Island is subject to some uncertainty and may be a little greater than that observed at Baltimore.

Marsh Degradation

Saltmarsh vegetation exhibits distinct zones with respect to elevation although brackish marshes do not always follow these zonations exactly (KEARNEY and STEVENSON, 1991). The low marsh is dominated by *Spartina alterniflora* and located between mean sea-level and high tide. The high marsh forms a nearly horizontal plain which coincides with the mean high tide level. *Spartina patens* and various types of *Juncus* are found at this level. At slightly higher elevations, plant species such as *Scirpus robustus* and salt marsh shrubs such as *Myrica cerifera* can be found. The high marsh is only completely flooded during spring high tide and storm events (LEATHERMAN, 1988).

A marsh has the ability to maintain its relative elevation in conformity with slowly rising sea level by vertical accretion due to biogenic and inorganic sediment inputs. However, when the rate of relative sea-level rise exceeds marsh accretion, inundation, erosion and submergence of the marsh ensues (STEVENSON et al., 1986). A primary mechanism of marsh deterioration and loss is interior ponding; as the sea level rises, ponds form, enlarge, and coalesce (KEARNEY et al., 1988). In addition, channel widening and upstream extension can be an important contribution to land loss. In areas exposed to wave action, such as in the Delaware Bay, rapid marsh edge retreat, locally exceeding 5 m/yr can also occur (PHILLIPS, 1986).

Chesapeake Bay Island and Marsh Studies

The islands in the Chesapeake Bay have shown significant losses since colonial times, particularly

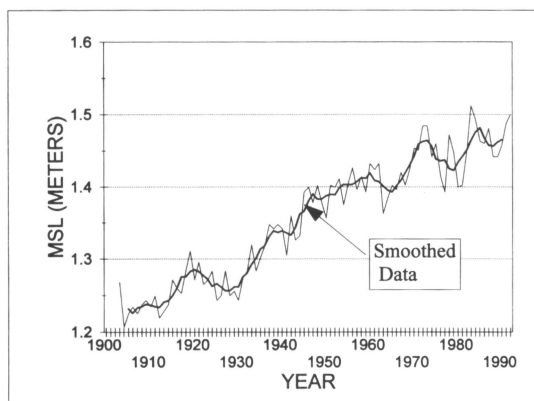


Figure 2. Annual mean sea-level record for Baltimore from 1903 to 1992. (Data from LYLES et al., 1988, supplemented by unpublished NOS data from 1987 to 1992). A five-point running mean for sea level is also shown.

since the 1850's (KEARNEY and STEVENSON, 1991). At least thirteen islands have totally disappeared (LEATHERMAN et al., 1993). WRAY (1992) examined the processes and rates of land loss for seven of the islands in the Bay, including Bloodsworth Island. The large marsh islands of Bloodsworth, South Marsh and Smith showed significant losses (16, 28, and 29 percent, respectively) around their perimeter, primarily due to wave erosion. However, interior land loss was not measured.

Two coastal marshes on the eastern shore of the Chesapeake Bay have been more extensively studied. STEVENSON et al. (1985) identified the importance of marsh loss due to interior pond formation at Blackwater National Wildlife Refuge. About 2,308 ha, or one-half of these submerged upland marshes converted to open-water from 1938 to 1979, at an average loss rate of over 56 ha/yr. KEARNEY et al., (1988) studied changes in the coastal marshes along the Nanticoke River, a typical marsh-dominated tributary to the Chesapeake Bay (Figure 1). They identified three processes of marsh loss: shore erosion along the estuary stem, channel-bank and apical erosion of channels, and interior pond formation. Cumulative losses were rapid and averaged 49.6 ha/yr from 1938 to 1985. In surviving marshes, declining plant density and increasing waterlogging was measured, using an integer marsh-surface-condition index. This trend was most apparent in the submerged upland marshes at the mouth of the

Nanticoke and indicates an increased vulnerability of much of the surviving marsh to total loss.

METHODS

The temporal and spatial analysis of land loss presented in this paper is part of a larger GIS study of Bloodsworth Island (DOWNS and HAUTZENRODER, 1992; DOWNS *et al.*, 1993). A GIS environment has proved to be excellent in handling the complex topology of the wetland/water interface.

The historical comparison of island change was conducted by delineating wetland/water and upland/wetland boundaries into ARC/INFO GIS. A number of sources were used and are listed in Table 2. The smallest object delineated in this analysis was about 16 m diameter, and this scale limitation should be noted when considering the results. (More detailed analysis of the island to a resolution of approximately 6 m is in progress).

Knowledge of the error inherent in the quantitative study is crucial, particularly for the 'T' sheets which depend on detailed ground surveys. SHALOWITZ (1964) notes that NOS 'T' sheets are the most accurate maps for delineating shorelines. Further, similar studies support the accuracy of such sources for this type of analysis (KEARNEY *et al.*, 1988; BRITSCH and DUNBAR, 1993). Worst case error estimates for position of the land/water boundaries are thought to be less than 8.9 meters, plus sketching error (CROWELL *et al.*, 1991). The wetland/upland boundary may contain larger errors due to greater difficulty in ground identification. SHALOWITZ (1964) notes that the accuracy of the wetland/upland boundary on the early NOS 'T' sheets tended toward generalization. Further, the classification of wetland or upland is uncertain as it is best based on pedological criteria. In this paper, upland refers to areas characterized by large bushes and trees, recognizing that some of these areas may actually have been high elevation wetlands.

Following the same general scheme as KEARNEY *et al.* (1988), the observed land loss can be divided into four geomorphic types (Figure 3):

- (1) perimeter land loss
- (2) channel widening and extension
- (3) channel ponding
- (4) non-channel ponding

Collectively, (2), (3), and (4) produce all the interior land losses. A channel is a long narrow body of water, and it may widen or increase its length

Table 2. *Data sources.*

Year	Data	Scale	Comments
1849	NOS 'T' Sheet	1:20,000	
1901	NOS 'T' Sheet	1:20,000	Not included in data set due to rotational error—used qualitatively.
1938	Black & White vertical aerial photography	1:12,000	Not included in data set—could not be resected. Used qualitatively.
1942	NOS 'T' Sheet	1:20,000	
1952	Black & White vertical aerial photography	1:12,000	Only used for perimeter land loss due to inability to distinguish interior features.
1973	USGS Orthophoto topo quad	1:24,000	Only used for perimeter land loss due to inability to distinguish interior features.
1992	Color Infra-Red vertical aerial photography	1:11,000	

with time. Ponds can form or enlarge in two situations: channel ponds which are on the drainage network, usually at the head of a channel; or non-channel ponds which are not connected to an obvious surface channel. These interior land loss types are important as, in general terms, they can be interpreted as indicating inundation due to relative sea-level rise. Channel widening and extension can be primarily attributed to tidal action with the increased flows brought on to the marsh surface by rising sea-level. Ponds primarily form due to a deficit of sediment or organic input. The increased waterlogging kills the marsh plants, and the exposed substrate is removed by other processes such as wave action. Ponds could also be formed by bombing; this problem is considered later.

Perimeter land loss is primarily due to erosion from wave action with sea-level rise as an underlying driver; a vertical edge consistent with wave erosion is noticeable around the perimeter of most of the island.

Comparison of the island from different time periods defines an area of land loss. Partitioning this land loss into the four geomorphic types requires an objective definition of the island perimeter. Generally, this is straight-forward, except at channels which flare in a seaward direction. Here

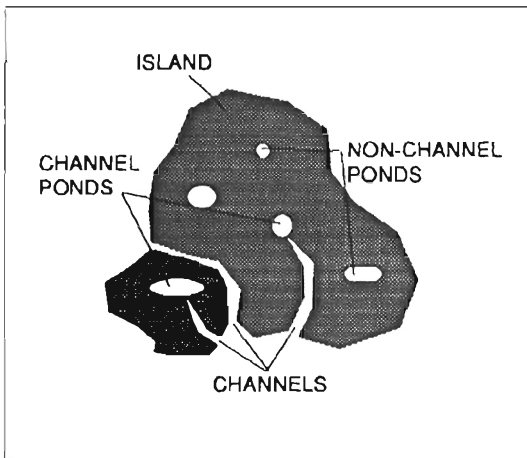


Figure 3. Definition sketch for the four geomorphic types of land loss.

an arbitrary division is necessary and this was based on a channel width of about 200 meters.

It is worth noting that a similar, and necessarily more complex geomorphic and process classification, has been independently developed for application in coastal Louisiana (WAYNE *et al.*, 1993).

RESULTS

Bloodsworth Island declined by 579 ha from 1849 to 1992, for a loss of about 26% of the total land area in 1849 (Figure 4; Table 3). From 1849 to 1942, almost 206 ha eroded from the perimeter. This represents an average loss of about 100 meters around the island's perimeter. Erosion is concentrated on the 'headlands', or more accurately, the protrusions of Bloodsworth Island. Hence, the perimeter shoreline of the island is being straightened and shortened. The maximum recession (132 meters) occurred on a protrusion on the northwest side of the island that is exposed to the greatest fetch ('X' Figure 4); the minimum recession (31 meters) occurred on the relatively sheltered eastern side of a cove on the south of the island ('Y' Figure 4). Fifty years later, in 1992, the pattern of perimeter erosion remained similar. The average perimeter loss since 1849 increased to 147 meters. The maximum recession (213 meters or 1.5 m/yr), and the minimum recession (62 meters or 0.4 m/yr) remained in the same locations.

Significant interior land loss has also occurred since 1849 with 141 ha lost by 1942, increasing to

Table 3. Total land area, and land loss by geomorphic type, versus time.

Year	Total Land Area (ha)	Perimeter Loss Since 1849 (ha)	Channel Widening (ha)	Channel Ponding (ha)	Non-Channel Ponding (ha)
1849	2,270.0	n.a.	n.a.	n.a.	n.a.
1942	1,927.4	205.7	64.4	73.9	2.3
1952	n.a.	221.9	n.a.	n.a.	n.a.
1973	n.a.	273.7	n.a.	n.a.	n.a.
1992	1,691.0	356.8	101.8	103.1	17.1

n.a. not available

222 ha in 1992 (Table 3). Channel widening and extension caused 102 ha of land loss. There is no evidence of meandering; channel position is stable, although the width increases with time. From two channel ponds of 8 ha mapped in 1849, the number increased to 127 in 1992, with two channel ponds in the southwest quadrant with areas of 25.6 and 19.5 ha, respectively (Figure 4). There were 118 non-channel ponds in 1992, the largest occupying one hectare. In general, the non-channel ponds are substantially smaller than the channel ponds.

Perimeter land loss accelerated from 2.2 ha/yr from 1849 to 1942 to 3.0 ha/yr during the next fifty years. Within the resolution of the data, this acceleration in land loss occurred after 1973 with average rates of loss of 4.7 ha/yr up to 1992. The increased rate of loss could be due to a greater number of more intense storms. ROSEN (1978) found that peat may reduce erosion during small storms. With more intense storms, large clumps of peat can be removed, making the marsh more vulnerable to erosion.

The rate of interior land loss also increased slightly from 1.5 ha/yr from 1849 to 1942 to 1.6 ha/yr from 1942 to 1992 and remained less than the rate of perimeter loss. To examine spatial patterns of land loss, the island was divided into quadrants, using the geomorphic center of gravity of the island in 1849 as an arbitrary, but consistent reference point (Figure 4).

Perimeter Land Loss

The predominant type of land loss in the northwest, northeast, and southeast quadrants is perimeter loss (Figure 5, Table 4). From 1849 to 1942, shore erosion was responsible for 80% of the total loss in the northwest quadrant, 77% in

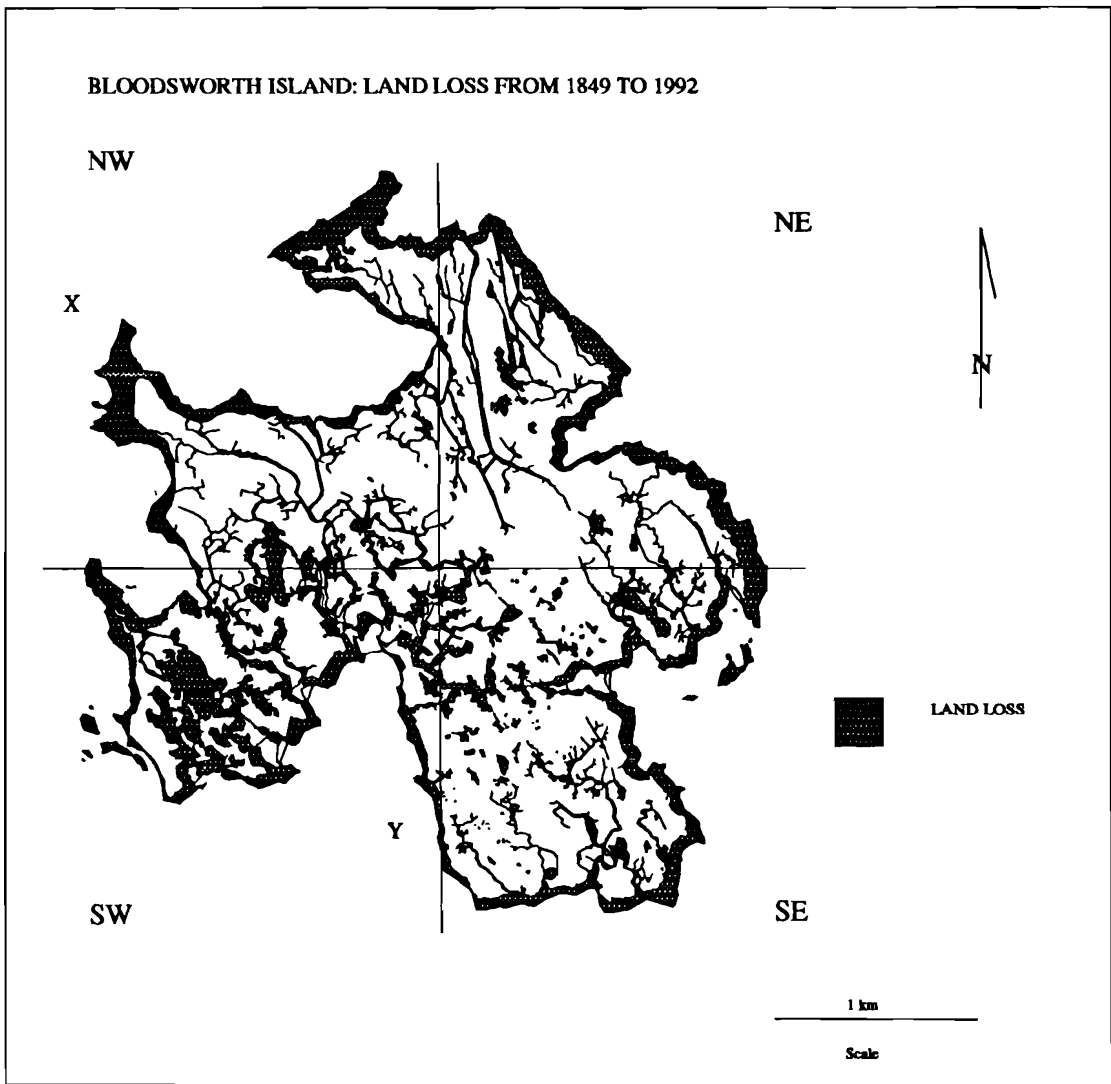


Figure 4. Land loss on Bloodsworth Island from 1849 to 1992, and the quadrants (NE, SE, SW, and NW). 'X' signifies the location of maximum perimeter recession and 'Y' signifies the location of minimum perimeter recession.

the northeast quadrant, and about 53% in the southeast. In the southwest quadrant, interior land loss was dominant and perimeter land loss was only 35% of the total loss. From 1942 to 1992, perimeter land loss was dominant in all quadrants (Figure 5). A relative decrease in perimeter loss in the northeastern quadrant and an increase in the southwestern quadrant probably represents an increase in southwesterly winds and/or a decrease in northeasterly winds.

Interior Land Loss

From 1849 to 1992, channel widening and channel ponding occurred at an approximately constant rate with time (Figure 6). These results understate the importance of channel widening because, as channels widen and ponds grow, areas formerly classified as channel progressively become incorporated within ponds. While the land loss which has been reclassified in this analysis is

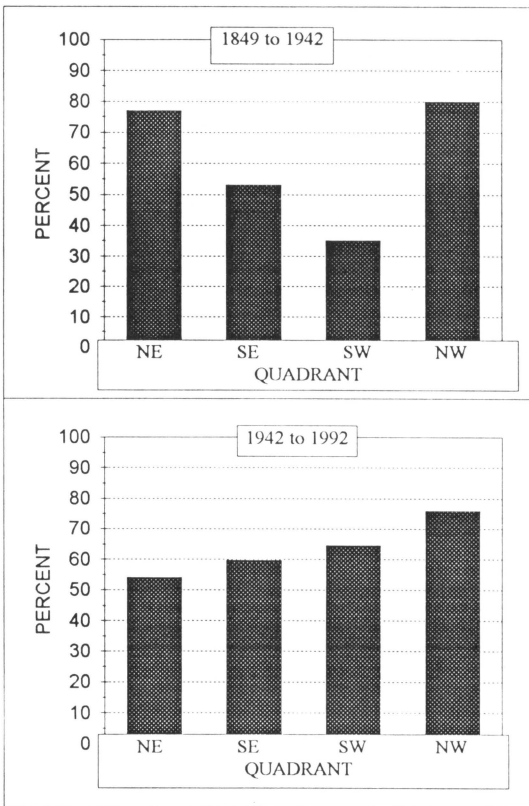


Figure 5. Perimeter land loss as a percentage of total land loss for each quadrant.

relatively small in area, it has increased with time. From 1849 to 1942, approximately 0.3 ha or 0.5% of the area occupied by channels in 1849 was reclassified as channel ponds; while from 1942 to 1992, over 6 ha or 6% of the channel area in 1942 was reclassified as channel pond.

The occurrence of non-channel ponds is especially noteworthy. On the 1849 and 1902 NOS 'T' sheets, there are no non-channel ponds; on the 1942 NOS 'T' sheet about 2.3 ha of non-channel ponds are shown, and non-channel ponds are also visible on the 1938 photography. From 1942 to 1992, non-channel ponds increased significantly in area to over 17 ha. In the same period, only five non-channel ponds, with a total area of 0.1 ha or 4% of non-channel ponds in 1942, were reclassified as channel ponds. While the accuracy of the source materials can be debated, the appearance of non-channel ponds between 1901 and 1938 is considered a significant change by the au-

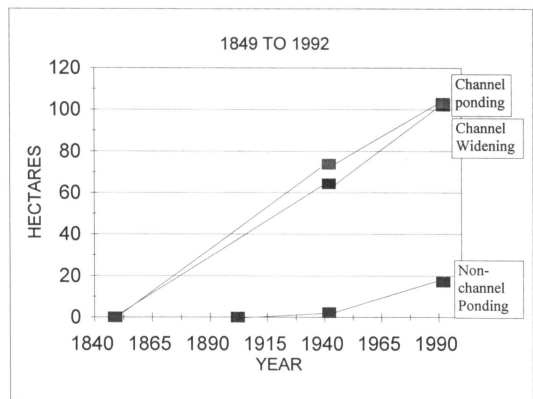


Figure 6. Interior land loss, by geomorphic type, from 1849 to 1992.

thors. The formation of non-channel ponds accounts for 18% of the interior land loss observed post-1942.

Interior land loss was also quantified by quadrant using the same method as with perimeter land loss. From 1849 to 1942, the southwest quadrant shows the greatest interior land loss, with approximately half the losses (Table 4; Figure 7). From 1942 to 1992, interior losses are more evenly distributed between quadrants. This reflects a decrease in the rate of interior loss in the southwestern quadrant, combined with an increase in the northern quadrant.

Comparison of the spatial pattern of land loss with each of the four quadrants from 1849 to 1942 and 1942 to 1992 (Figure 8) demonstrates that the same land loss types remain dominant. The major change is the increase in non-channel ponding in the two eastern quadrants with the largest increase in the southeast quadrant—from 2.6% to 56% of interior loss. At the same time, formation of channel ponds almost ceased in this quadrant. The northwest quadrant had no non-channel ponds in 1942, but 0.1 ha had formed by 1992.

Table 4. Land loss by quadrant—from 1849 to 1992.

Year	Exterior Land Loss (ha)				Interior Land Loss (ha)			
	NE	SE	SW	NW	NE	SE	SW	NW
1849	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
1942	47.8	48.3	34.5	75.1	14.1	42.6	65.4	18.5
1992	68.1	81.3	82.5	124.9	31.3	64.8	91.5	34.3

The major drainage channels and ponds were concentrated in the southwest and southeast of the island in 1942 (Figure 9). Except in the southwest quadrant, extensive areas of intact marsh existed over much of the island. By 1992, the formation or extension of interior channels and ponds had broken much of the intact marsh, and greatly increased the length of marsh/water interface within the island (Figure 9). This suggests that the island has become more vulnerable to interior break-up with time. An interesting note is that a number of large ponds formed between 1849 and 1942, mainly in the southwestern quadrant. These ponds showed much smaller growth from 1942 to 1992.

Upland to Wetland Conversion

Another important factor related to sea level position is the amount of upland or higher ground. Even in 1849, only 59 ha or 2.5% of the island was designated as upland on the NOS "T" sheet. This upland area was not continuous and comprised 39 distinct areas, mainly in the northern half of the island, with smaller areas in the south. By 1973, 79% of the upland in 1849 was lost, primarily due to upland and wetland conversion; only four areas of upland in the northeast quadrant remained. Due to the scale of the maps and the subjectivity of the surveyors and map illustrators, these results should not be over-interpreted. However, these results along with anecdotal data of the last loblolly pines dying during the 1960's show a consistent trend of higher land converting to lower elevation wetlands.

In earlier phases of the history of Bloodsworth Island, the process of upland to wetland conversion may have replaced the loss of wetlands. However, since 1849, the rate of conversion (about 0.4 ha/yr), which is limited by the lack of available upland, has been insufficient to compensate for wetland loss.

DISCUSSION

Land Loss and Sea-Level Rise

From 1849 to 1992, Bloodsworth Island experienced a significant rise in relative sea level. Based on the Baltimore tide gauge, a measured rise of 0.28 meters has occurred since 1903, with a more speculative estimate of a rise of over 0.4 meters since 1849. At the same time, Bloodsworth Island declined by 579 ha, or 26% of the land area in 1849.

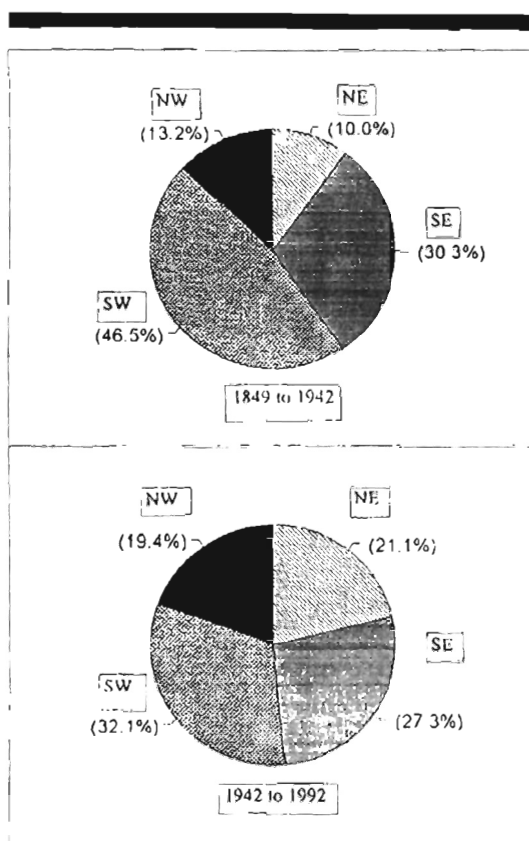


Figure 7. Total interior loss by quadrant.

Unlike the sheltered marshes on the mainland, Bloodsworth Island is exposed to wave activity, and perimeter erosion has been the dominant land loss process (Figure 5). This rate of land loss increased from 2.2 ha/yr, from 1849 to 1942, to 3.0 ha/yr from 1942 to 1992, corresponding to an annual loss of 0.18% of the 1992 island area. The rate of recession of the perimeter of Bloodsworth Island is not untypical of other similar locations. For instance, the marshes bordering Delaware Bay have experienced more rapid recession rates, averaging about 3 and 5.6 m/yr on the eastern and western shores, respectively (PHILLIPS, 1986, FRENCH, 1990).

The relationship between recession rates and sea-level rise on islands such as Bloodsworth is poorly understood. Bloodsworth is composed largely of a silt and clay substrate beneath thin marsh deposits, and most eroded material is readily suspended and carried offshore. Thin sand

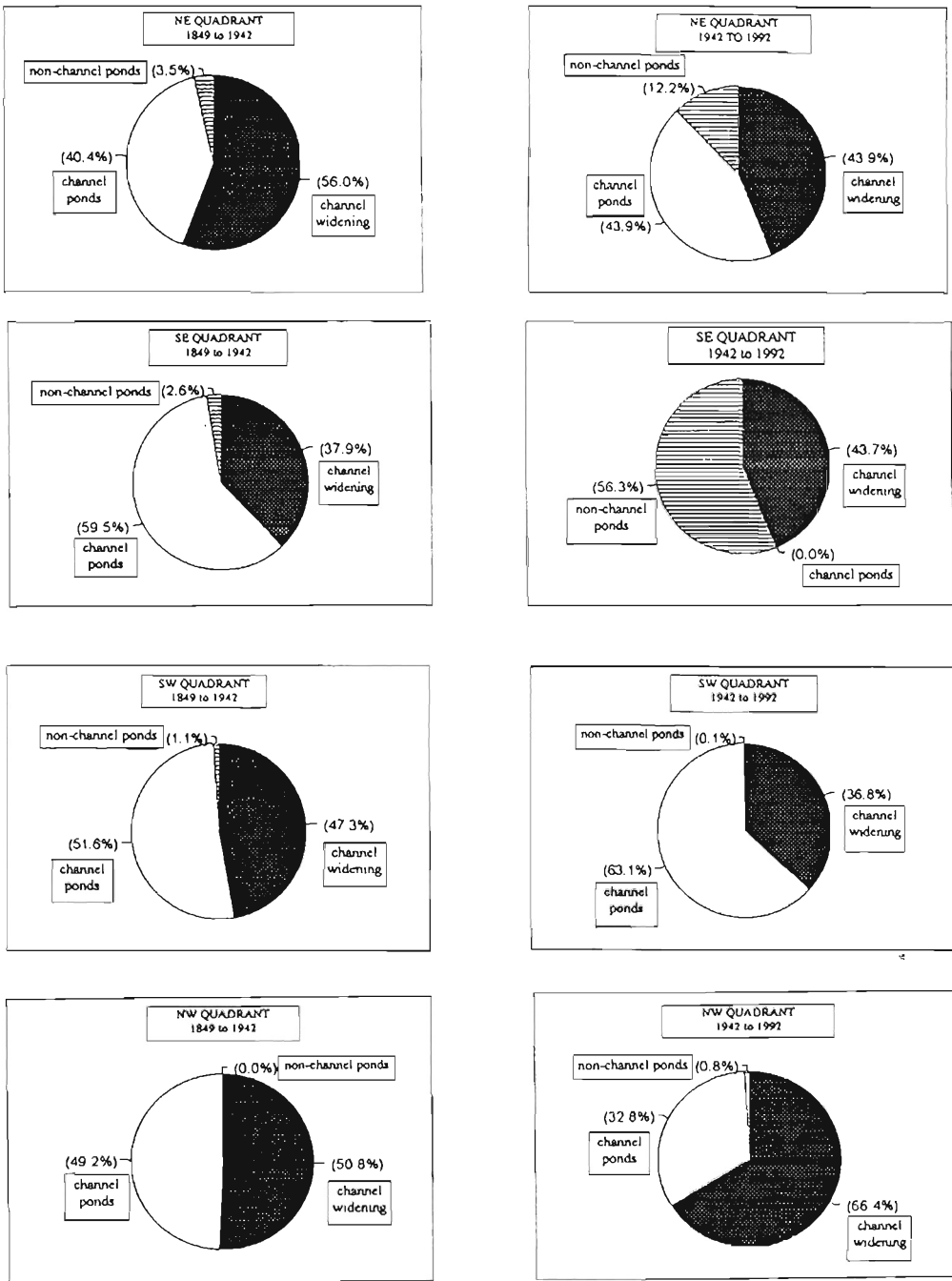


Figure 8. Comparison of the interior land loss types in each quadrant for the period 1849 to 1942, and 1849 to 1992.



Figure 9. Drainage and pond expansion on Bloodsworth Island from 1942 to 1992.

veneers are present over the marsh surface along the western and northern perimeters where erosion is most rapid but is insufficient to afford any significant protection from erosion. Multiple sand bars also occur off the western shore of the island. In Calvert County, on the western shore of the Bay, such bars are indicative of an offshore loss of sand (DOWNS, 1993). Therefore, the limited sand produced by erosion of Bloodsworth is probably lost offshore. Thus, without any further rise in sea level, erosion of Bloodsworth Island would be expected to continue. Under such a scenario, erosion rates would slowly decline towards some unknown background erosion rate, independent of sea-level rise. Acceleration of exterior land loss since 1973 indicates the importance of wind direction and storminess in the rate of shore erosion.

While interior land loss is less important than perimeter land loss, the processes of interior land loss are all promoted by sea-level rise. Channel widening and channel ponding are the dominant

interior land loss types. Within the coarse temporal resolution of the data, they appear to cause land loss at a similar rate. Overall, channel widening has been more important than channel ponding. In addition to the reclassification already discussed, some land loss due to channel widening will have been classified as channel ponding, particularly given the long interval between source materials.

The initiation of non-channel ponds between 1901 and 1938 and their subsequent increase is significant. Their initiation coincides with a short-term acceleration in sea-level rise in the Bay from 1930 to 1948 and is probably linked directly to marsh inundation. Marsh deterioration is also reported at this time in Blackwater National Wildlife Refuge (STEVENSON *et al.*, 1985) and the Nanticoke River (KEARNEY *et al.*, 1988). Expansion of the drainage system on Bloodsworth also occurs, and five non-channel ponds in 1942 were reclassified as channel ponds in 1992.

The observed interior wetland loss on Bloodsworth Island, including the accelerated losses since 1942, is consistent with a regional pattern of wetland loss. However, the rates of land loss on Bloodsworth Island are significantly smaller than those on the mainland. In the Nanticoke River losses from 1938 to 1985 averaged about 0.5% annually (49.6 ha/yr), with most losses occurring in the submerged upland marshes at the mouth of the river (KEARNEY *et al.*, 1988). At Blackwater, losses exceeded 1% annually (56 ha/yr) from 1938 to 1979 (STEVENSON *et al.*, 1985). In contrast at Bloodsworth Island, total land loss from 1849 to 1992, including perimeter losses, averaged 0.18% per annum (or 4.0 ha/yr). Considering the shorter period from 1942 to 1992, total land loss averaged 0.25% per annum (or 4.8 ha/yr). On Bloodsworth Island, enlargement of the drainage network, including the formation of tidal channel ponds, is the dominant interior land loss type. This differs from the patterns of interior land loss at Blackwater where non-channel ponding dominates.

The different patterns and rates of loss are probably related to the thickness of the marsh deposits. At Blackwater, much of the marsh deposits are 4 m thick and can almost be considered floatant with ooze beneath a marsh mat (STEVENSON *et al.*, 1985). In the Nanticoke, coring has shown the marsh deposits to be at least several meters thick (KEARNEY, *personal communication*, 1994). In contrast, at Bloodsworth the marsh deposits are generally one meter or less, overlying more resistant silts and clays. Thin marshes have been found to be less vulnerable to break-up in Louisiana (TURNER and CAHOON, 1987). It is also interesting to note that the ponds on Bloodsworth do not show a NE-SW orientation related to northeasters as described at Blackwater (STEVENSON *et al.*, 1985). Further, the large ponds existing in 1942 did not enlarge significantly in subsequent years. This suggests that wave action is less important in interior marsh loss on Bloodsworth than on the mainland marshes. The other large marsh islands in the Chesapeake Bay (Smith and South Marsh) have a similar geological history to Bloodsworth suggesting that they may also be less prone to internal break-up.

Marsh Surface Condition

In many areas on Bloodsworth Island, observations on high resolution color IR photography show that plant density has decreased, and the marsh is increasingly waterlogged. Such a decline

in plant density is not conducive to vector analysis. Therefore a five class marsh-surface-condition (MSC) index is being devised in a raster format (after KEARNEY *et al.*, 1988), ranging from: (1) a healthy, high plant density marsh; to (5) a total deterioration, or virtually open water. In effect, the MSC index divides the land class into four classes. This will provide a better indication of the future vulnerability of Bloodsworth Island to processes of interior land loss. Similar raster-based indices have been developed and found useful in describing and understanding patterns of marsh loss and degradation in coastal Louisiana (SASSER *et al.*, 1986, EVERS *et al.*, 1992).

Implications of Bombing

Another important consideration is the influence of bombing and shelling on Bloodsworth Island, both in terms of land loss and marsh condition. The southern part of the island was already undergoing wetland deterioration and land loss, including non-channel ponding, prior to the U.S. Navy purchasing the island in 1948. Therefore, the observed interior land loss was not initiated by bombing.

The influence of bombing on interior land loss since 1948 remains uncertain. Large-scale color infra-red photography (1:4,800) taken in 1992 showed that parts of the island is peppered with impact ponds from practice bombing, as small as one meter in diameter. Had the study been conducted at this scale, the measured interior land loss would have been greater, with a larger area of non-channel ponds being identified. However, after studying selected photographs, there is no clear evidence of the impact craters coalescing to form larger ponds in areas of healthy marsh. In more degraded marsh, impact ponds may accelerate total loss of the wetlands. Therefore, it is concluded that the patterns of land loss presented in this paper are primarily due to sea-level rise and wave action on the perimeter with only a secondary contribution from impact ponds.

More research is required regarding the future consequences of the impact ponds. This includes their interaction with sea-level rise and the associated interior land loss processes, MSC index, and other factors, such as the density of impact ponds. Such understanding is essential for optimal habitat and wildlife management of Bloodsworth Island.

In certain cases, the bombing improves wetland habitat for waterfowl. The impact ponds within

the black needle rush (*Juncus roemerianus*) support widgeon grass (*Ruppia maritima*), a submerged aquatic plant that is attractive to waterfowl. However, this benefit may be offset in the long-term if the impact ponds grow or coalesce and contribute significantly to land loss and deterioration of the island.

Habitat and Wildlife Management Implications

Continuing land loss at existing rates is not expected to significantly impact the island habitat over the next 20 to 30 years. The southwestern quadrant with annual losses of 1.5 ha/yr, or 0.6% is already heavily dissected by channels and ponds (Figure 4) and can be expected to see the most rapid changes. Rapid shoreline movement will occur when shore erosion connects the extensive system of ponds in this area with the bay.

Existing rates of land loss may underestimate the potential for future interior land loss. The extensive and expanding areas of interior water (Figure 9) suggest that the marsh is increasingly vulnerable to interior break-up. Qualitative observations of high values of MCI in parts of the marsh reinforce this conclusion. Therefore, the projected long-term acceleration in sea-level rise due to global warming would almost certainly accelerate interior land loss above the rates reported here. Based on the worst case scenario of WIGLEY and RAPER (1992), relative sea-level rise at Baltimore could be about 8 mm/yr by the year 2050. Of more immediate concern is another short-term acceleration of sea-level rise as occurred during the 1930's and 1940's. Based on the record at Baltimore, rates of relative sea-level rise could be 7 mm/yr for more than a decade. While the reasons for these short-term accelerations in sea-level rise are poorly understood, sharp accelerations have occurred in the past; therefore, there is no reason to believe that they won't occur again.

In the long-term, human intervention will be required to maintain the island habitat. This will necessitate perimeter protection to stop erosion and marsh restoration to combat the effects of interior land loss and sea-level rise.

CONCLUSION

This study has shown that Bloodsworth Island has changed significantly since 1849, and these changes are consistent with a sediment/biomass deficiency in the face of rising sea level. The limited areas which can be characterized as upland have been almost totally invaded by wetland veg-

etation, and the last large trees on the island died during the 1960's. The wetland areas have experienced significant losses of 579 ha (or 26%) from 1849 to 1992. These are due primarily to perimeter land loss driven by wave action, with a significant contribution from interior land loss. Non-channel ponds appear to have first formed between 1901 and 1938. The timing is consistent with a short-term acceleration of sea-level rise which increased wetland degradation in other parts of the Chesapeake Bay. The rate of interior land loss is less than the other documented sites in the area. This is due to the thin marsh deposits on Bloodsworth which are less prone to break-up and extensive non-channel pond formation. Hence, interior land loss is mainly attributed to channel widening and channel ponding. Bombing and shelling have also contributed to land loss, but its total contribution remains unknown. This study did not resolve ponds below a 16 m diameter, and there is little evidence of the impact ponds coalescing in areas of healthy marsh. Thus, the contribution of impact ponds to land loss is thought to be negligible.

This study confirms a picture of regional loss of wetlands in the Chesapeake Bay driven by high rates of relative sea-level rise. Land loss can be expected to continue on Bloodsworth Island at existing or possibly higher rates in the coming few decades. Given the deteriorating interior condition of the marsh, another short-term acceleration of sea-level rise may cause a significant acceleration of interior land loss. This conclusion may apply more widely to other wetland areas in the Chesapeake Bay and further afield.

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