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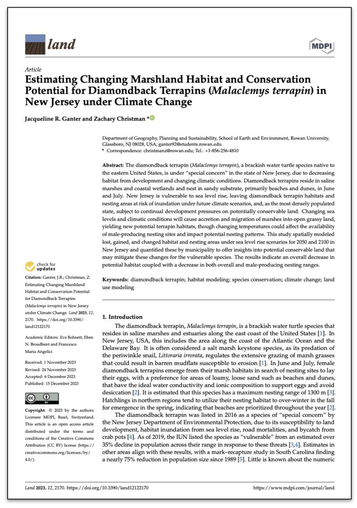
*Female diamondback terrapin crossing road in Ocean City, NJ*



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**Estimating Changing Marshland Habitat and Conservation Potential for Diamondback Terrapins (*Malaclemys terrapin*) in New Jersey under Climate Change**

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**Abstract:** The diamondback terrapin (*Malaclemys terrapin*), a brackish water turtle species native to the eastern United States, is under "special concern" in the state of New Jersey, due to decreasing habitat from development and changing climatic conditions. Diamondback terrapins reside in saline marshes and coastal wetlands and nest in sandy substrate, primarily beaches and dunes, in June and July. New Jersey is vulnerable to sea level rise, leaving diamondback terrapin habitats and nesting areas at risk of inundation under future climate scenarios, and, as the most densely populated state, subject to continual development pressures on potentially conservable land. Changing sea levels and climatic conditions will cause accretion and migration of marshes into open grassy land, yielding new potential terrapin habitats, though changing temperatures could affect the availability of male-producing nesting sites and impact potential nesting patterns. This study spatially modeled lost, gained, and changed habitat and nesting areas under sea level rise scenarios for 2050 and 2100 in New Jersey and quantified these by municipality to offer insights into potential conservable land that may mitigate these changes for the vulnerable species. The results indicate an overall decrease in potential habitat coupled with a decrease in both overall and male-producing nesting ranges.

**Keywords:** diamondback terrapin; habitat modeling; species conservation; climate change; land use modeling

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## Introduction

The diamondback terrapin, *Malaclemys terrapin*, is a brackish water turtle that resides in the saline marshes and estuaries, and nests on the beaches, along the New Jersey coast of the Atlantic Ocean and Delaware Bay (Hart and Lee, 2006; Wnek, 2010). Diamondback terrapins were listed in 2016 as a species of "special concern" by the NJ Department of Environmental Protection due to threats including habitat loss from sea level rise and anthropogenic development (DiLeo, 2016). New Jersey is especially vulnerable to sea level rise from its sinking land, and under moderate emissions, is expected to face 0.9-2.1 feet of rise by 2050, and 2.0-5.1 feet by 2100 (Kopp et al., 2019). Marshlands can respond to this by becoming completely inundated by water, accreting vertically with deposited sediment, or migrating inland into undeveloped areas (Weis et al., 2021). This suggests that the amount and location of future habitat will vary under different rise scenarios.

Diamondback terrapins also experience temperature-dependent sex determination, with eggs incubated above 29°C (84.2°F) producing females, and below producing males (Jeyasuria and Place, 1997). With New Jersey expecting to experience an increase of 3.5°F in air temperature by 2050, and 7.75°F by 2100, sex ratios have the potential to skew towards female (Runkle, et al., n.d.). The purpose of this project is to evaluate the potential impact of sea level rise and increased air temperature on diamondback terrapin habitat, nesting area, and sex-ratios.

## Study area and methods

This study focused on the coastal region of New Jersey along the Atlantic coast and Delaware Bay, which comprises their traditional range. Land use data was used as a basis for current potential diamondback terrapin habitats. This was quality-checked using methods by Al-Maliki and colleagues, by creating a combined layer of NDWI, NDMI, and NDVI thresholds from Landsat 8 imagery that defined areas unsuitable for marshlands. USDA Soil Survey Geographic Data was used to select nesting area of suitable substrate, and was reclassified with sex-based temperature thresholds from Landsat 8 thermal imagery. Projected marsh migration and accretion data was downloaded from Duke University.

Protected land was determined from areas under the Green Acres Program, preserved natural areas and protected tidelands by the NJDEP, and the US GAP analysis project. Sea level rise layers were created by reclassifying a LiDAR-derived Digital Elevation Model from NJOGIS using projections of the 17% and 83% likelihood scenarios for 2050 and 2100 from the 2020 New Jersey Scientific Report on Climate Change. This layer was used to eliminate future inundated marshlands. Nesting area was reclassified using projected temperature increases from the report. The results were further determined by municipality.

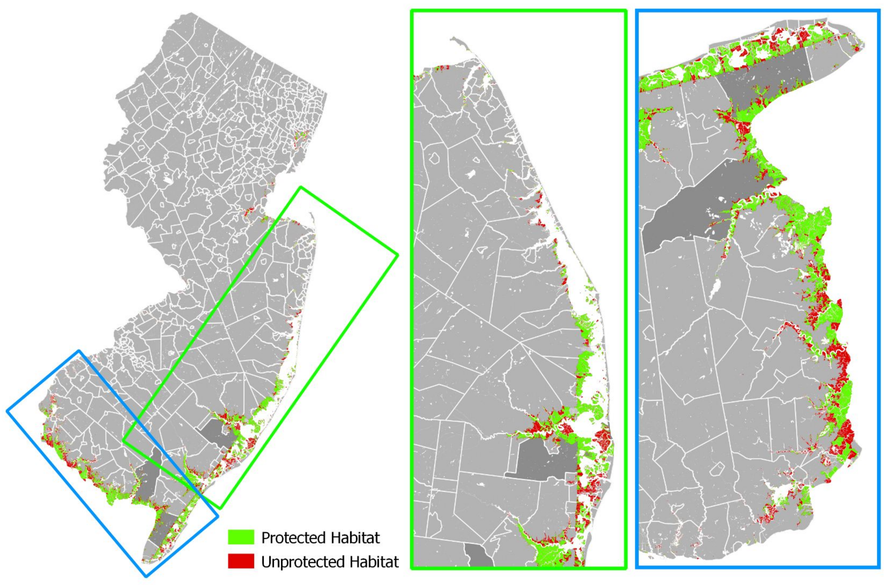


Figure 1. Protected and unprotected diamondback terrapin habitat in New Jersey

## Results

The results show that diamondback terrapins are expected to lose a substantial amount of original habitat, with up to 99.44% lost in the most severe scenario. This is slightly mitigated with the development of new marsh, with a projected 31.90% of new habitat gained in the most severe scenario. The amount of overall habitat protected is projected to decrease to 49.96%.

Similar results are expected for nesting area, with a projected loss of 50.70% of original area in the most severe scenario. Of this, only 43.15% is expected to be protected. The sex-ratio of nesting area is expected to skew towards female, with only 0.34% of nesting area able to produce males in the most severe scenario.

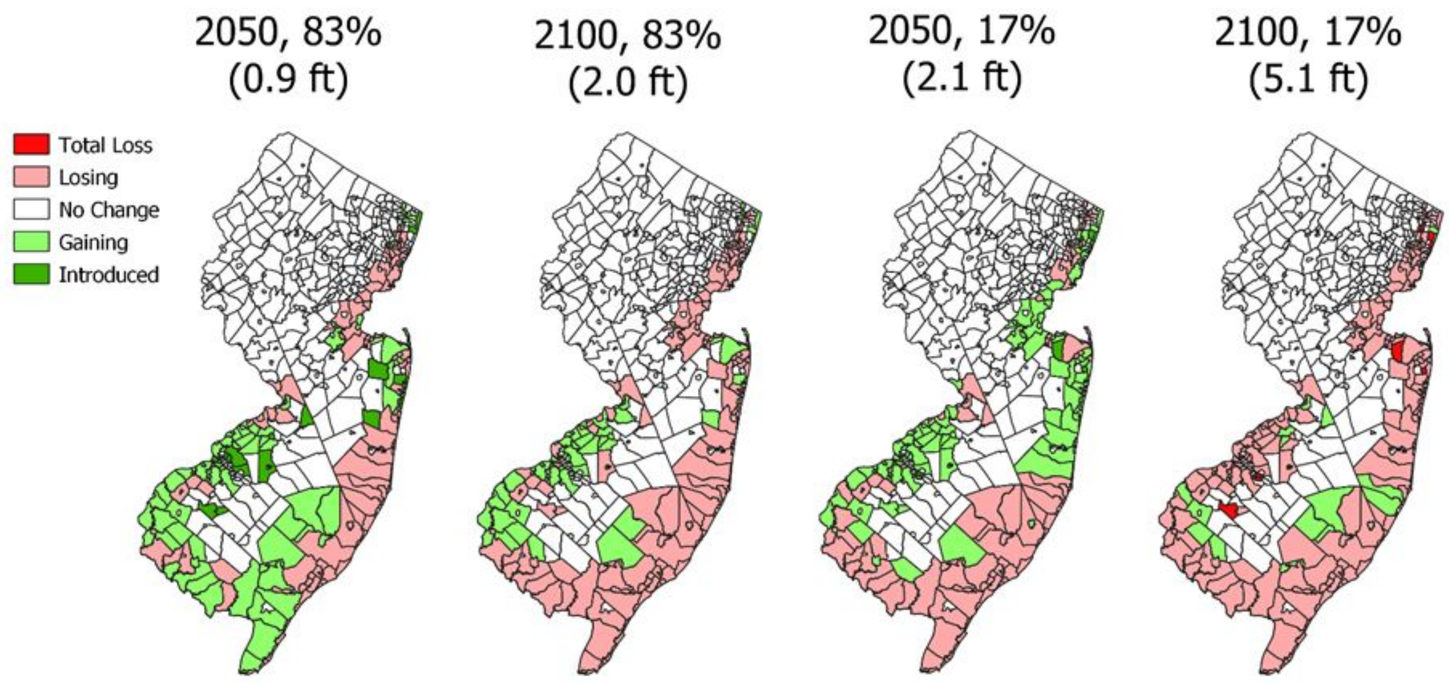


Figure 2. Trend cases in habitat area from each previous scenario by municipality

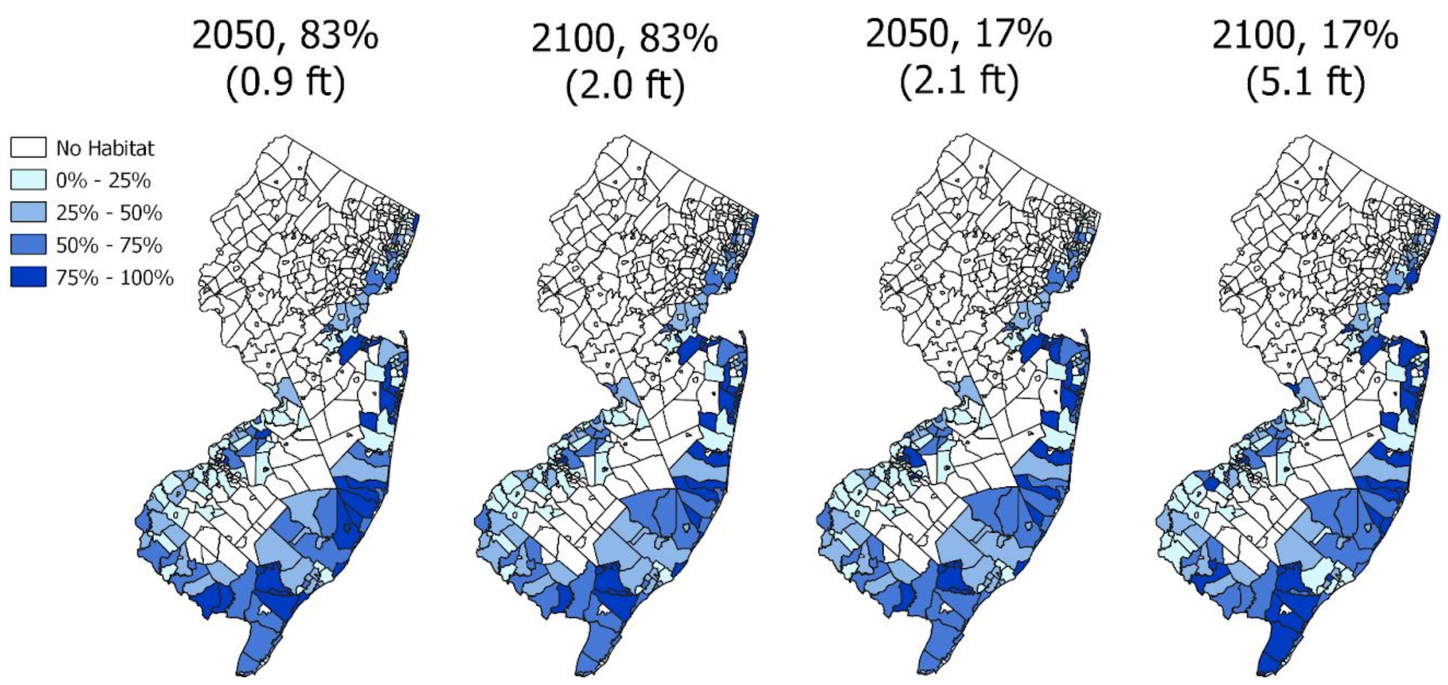


Figure 3. Percentage of protected habitat in each municipality by area under each sea level rise scenario

| Scenario | SLR (ft) | Temperature Increase (°F) | Habitat Gained (%) | Habitat Lost (%) | Nest Area Lost (%) | Male Nesting Area (%) | Habitat Protected (%) | Nest Area Protected (%) |
|---|---|---|---|---|---|---|---|---|
| Current | 0 | 0 | 0.00% | 0.00% | 0.00% | 8.69% | 65.41% | 57.72% |
| 2050 (83% confidence) | 0.9 | 3.5 | 22.96% | 15.04% | 7.50% | 1.51% | 62.62% | 56.50% |
| 2100 (83% confidence) | 2 | 7.75 | 28.81% | 54.03% | 12.15% | 0.44% | 58.14% | 56.09% |
| 2050 (17% confidence) | 2.1 | 3.5 | 27.16% | 59.21% | 12.88% | 1.27% | 57.14% | 55.48% |
| 2100 (17% confidence) | 5.1 | 7.75 | 31.90% | 99.44% | 50.70% | 0.34% | 49.96% | 43.15% |

Table 1. Changes in habitat and nesting area under each sea level rise scenario

## Discussion

While varying by scenario and municipality, the results show a substantial decrease in habitat with sea-level rise, especially along the eastern Delaware Bay and east coast, which consists of their traditional range. This loss of habitat may force the species to become displaced, moving where marshes are migrating. Marshes are projected to move inland along tributaries and bays, and near the coast of the Delaware River in southwestern New Jersey and the central-eastern coast. Western movement, however, may prove challenging, as the Delaware River's unsuitably low salinity (Pyle and Fehring, 2020) could decrease body size (Holliday, Elskus, and Roosenburg, 2009) or lead to an invasive species event where diamondback terrapins increase the competition for resources in the area (Polo-Cavia, López, and Martín, 2011). Furthermore these areas lack proper nesting area, and conserved area, potentially exposing the species to hazardous urban areas. Said municipalities should consider conserving more of their open areas that have the potential to become future habitat.

Nesting area is similarly expected to decrease with sea level rise, primarily along the east coast and Delaware Bay. This may force diamondback terrapins to settle for less suitable substrate, potentially lowering the chances of hatching success (Wnek, 2010). Moreover, the percentage of nesting area able to produce males may decrease to unsustainable levels (Heppell, Wyneken, and Heppell, 2022). Carefully planned dredging, along with cooling strategies, such as increased dune vegetation, may increase available male nesting area (Wnek, 2010).

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