Appendix 2: Geomorphic Analysis

Jeremy Lowe, San Francisco Estuary Institute

Introduction

The restoration strategy and alternatives are designed to provide a mosaic of functional and resilient habitats in the Lower Sonoma and Tolay Creek watersheds. This section of the plan evaluates how well each of the alternatives succeeds at achieving this goal up to 2100 based on the designs of the alternatives and habitat evolution in response to sea level rise.

Of particular concern is the potential increase in flow rates along the tidal channels of Sonoma Creek as tidal action is restored to diked areas either by design through restoration projects, or by accident due to erosion and breaching of dikes. The presently diked parcels are very large areas of subsided land which, since they lie within the tidal range, will fill and empty on each tide. The volume of water that enters on the flood and leaves on the ebb is called the tidal prism and is conveyed to and from the marsh by the remaining tidal channels. The present tidal prism is relatively small, since most areas are protected by dikes, and many of the channels have been filling in with marshes. If the tidal prism increases, then these channels will erode to a size that allows them to convey the increased volume of water. Erosion of the channels to convey water may result in erosion of the existing fringing infill wetlands and dikes, and scouring around bridge piles. It is therefore essential to estimate the future widths of the main channels if tidal prism is increased.

Methods

The relationship between channel size at a particular cross-section of a channel and some measure of flow discharge (such as tidal prism) upstream of that cross-section is known as hydraulic geometry. The hydraulic geometry relationships for marshes in San Francisco Bay have been investigated by Williams et al. (2002) for marshes in San Francisco Bay. In that study, empirical correlations between channel cross-section morphology (width, depth, area) and tidal prism for a San Francisco Bay data set were used to predict equilibrium cross-section morphology for a given tidal prism. For each cross-section were characterized:

- Depth, *D* (m) - depth relative to MHHW at the deepest part of the cross-section, the thalweg;
- Width, *W* (m) - distance between the two banks at MHHW, or projected to MHHW if the banks were lower;
- Cross-sectional area, *A* (m^2) - area below MHHW for the part of the channel within the channel width;
- Diurnal Tidal prism, TP (m^3) - volume of water between MLLW and MHHW within the contributing tidal watershed area landward (upstream) of the cross-section, extending to the drainage divide between channel networks.

The dataset included the historical pre-diked Sonoma Creek, Petaluma River and Napa River, as well as modern channels within ancient marshes such as China Camp, Heerdt Marsh, Petaluma Marsh and Wildcat Marsh (**Figure 1**).

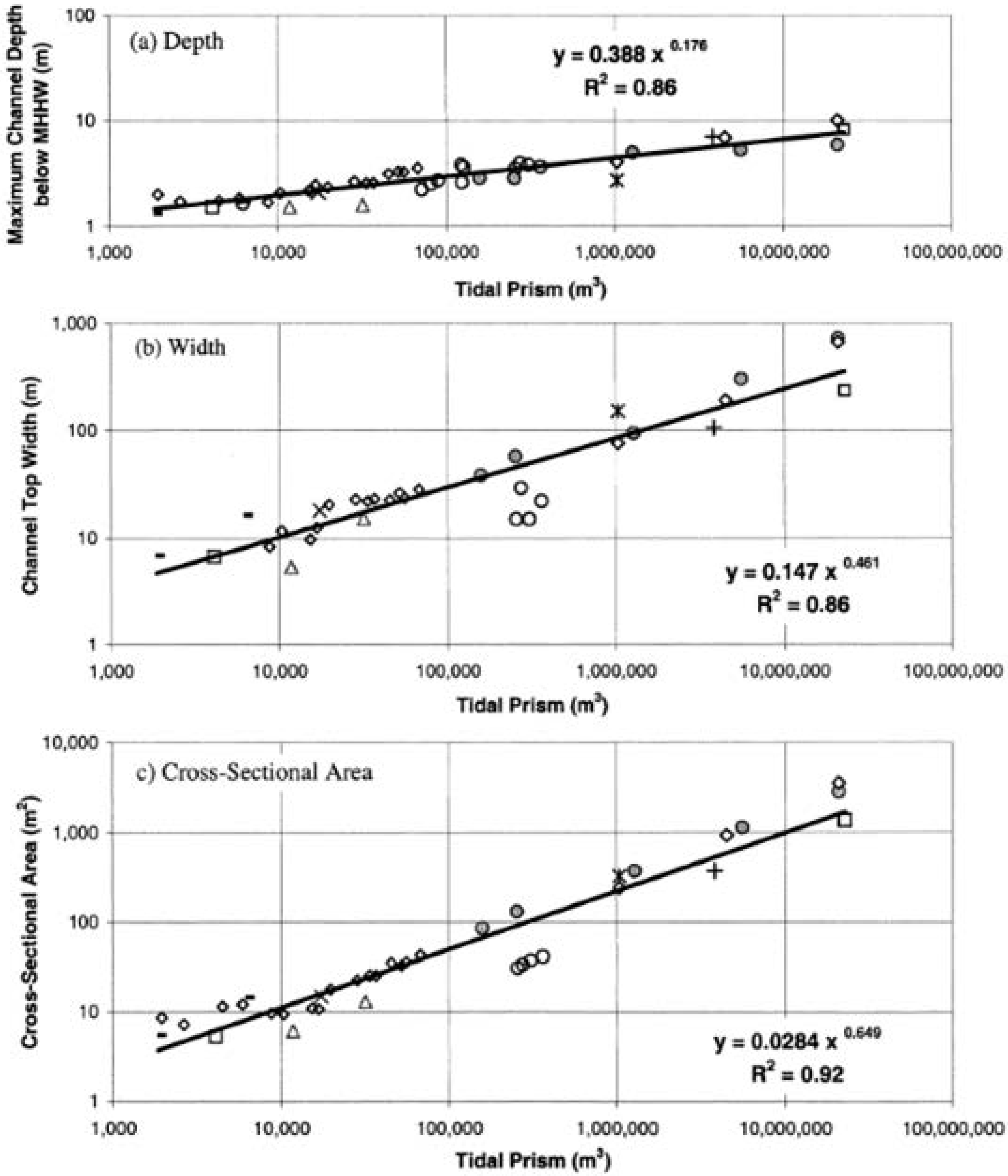

Figure 1. Depth, width, and cross-sectional area versus diurnal tidal prism for ancient marshes in San Francisco Bay (Figure 6 from Williams et al. 2002).

From the analysis of the historical and present-day marsh channels, Willams et al. determined the following hydraulic geometry relationships:

$$D = 0.388\,TP^{0.176};\; W = 0.147\,TP^{0.461};\; A = 0.0284\,TP^{0.649} \quad \text{Eq. 1-3}$$

Tidal prism was calculated. **Table 1** shows the tidal datum and extreme total water levels for Sonoma Creek calculated as part of their recent FEMA remapping of the Bay (AECOM 2016):

Table 1: Present (2000) tidal datum and extreme water surface elevations for Sonoma Creek.

		Elevation ft (m) NAVD88	
Extreme water levels	100-year total water level	9.74 (2.97)	100-year storm surge is 3.5ft (1.07m)
	10-year total water level	8.53 (2.60)	
	1-year total water level	7.48 (2.28)	
Daily Tides	Highest Astronomical Tide (HAT)	7.71 (2.35)	Tide range is 5.8ft (1.76m)
	Mean Higher High Water (MHHW)	6.23 (1.90)	
	Mean Sea Level (MSL)	3.48 (1.06)	
	Mean Lower Low Water (MLLW)	0.46 (0.14)	

The net effect of diking and draining was a dramatic loss of tidal marsh habitat, the creation of discrete diked bayland parcels, a significant reduction in tidal prism, and the creation of a significant sediment trap in the historical channels. The former marshes have subsided by several feet below MHHW , and the whole area is dependent upon levees and pumping to prevent flooding.

Elevations for all parcels except West End and Detjen were derived from Sonoma County Veg Map's 3ft bare earth LiDAR-derived DEM (2013). West End and Detjen elevations were derived from CA Ocean Protection Council's 3.3 feet (1 meter) LiDAR-derived DEM (2010). **Figure 2** shows that most of the diked baylands have subsided to an elevation at about MLLW (0.43 ft/0.13 m NAVD88). Camps 1-4 and Skaggs Island are all clustered around this elevation, with Camp 3 the lowest-lying parcel at a mean ground elevation of -0.05 ft /-0.01m NAVD88. The Ringstrom Bay, West End, and Detjen units have average elevations equivalent to low marsh (between 4.22 ft/1.29m and 5.04 ft/1.54m, according to Takekawa et al. 2013). On the alluvial fan, south of SR 121, Area 4 is at high marsh elevation, and Area 3 has an average elevation above the tidal range.

Average elevations for each parcel of interest are shown in **Figure 3** and reveal a north-south gradient from the alluvial fan south of SR 121 to the diked marshes further south.

Potential tidal prisms for each parcel are shown in **Figure 4**. These volumes were calculated for void space between the present ground surface and MHHW. The volumes were approximated based on hypsometric curves generated for each parcel using Sonoma County Veg Map's 3ft bare earth LiDAR-derived DEM (2013) (and OPC's 1m LiDAR-derived DEM (2010) for West End and Detjen) and are estimates only. Skaggs Island has the largest potential tidal prism, as a large area at relatively low existing elevation (an average of 0.99 ft/0.30m NAVD88). Camps 3 and 4, other large and low-lying parcels, also have large potential tidal prisms. In comparison, smaller and higher parcels like Camps 1-2, Detjen, and West End, have smaller potential tidal prisms. Tubbs Island is shown for comparison.

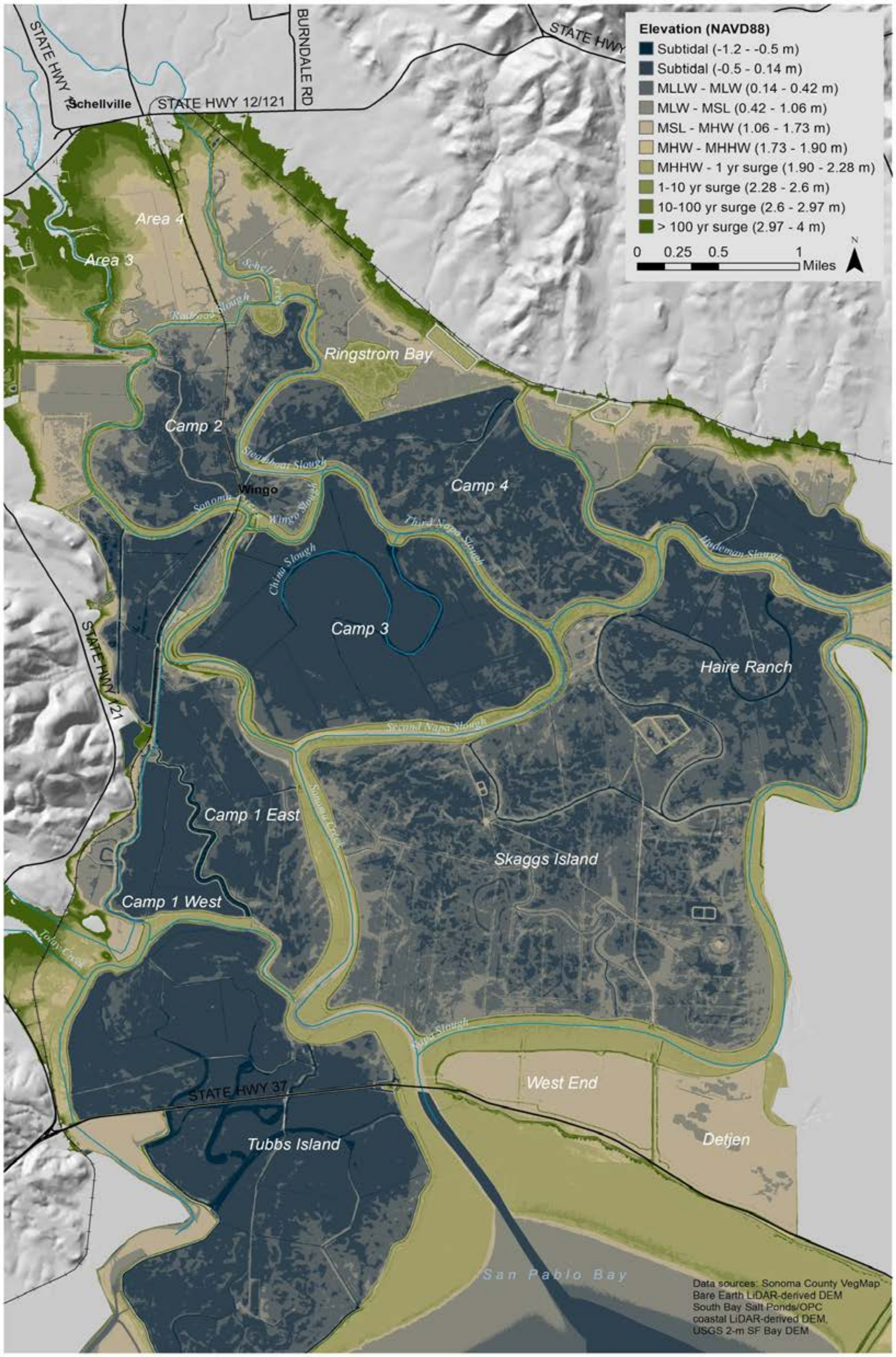

Figure 2. Present day topography of the broader Sonoma Creek area following diking. Digital elevation model sources: South Bay Salt Pond/OPC coastal Lidar-derived DEM, USGS 2-m SF Bay DEM.

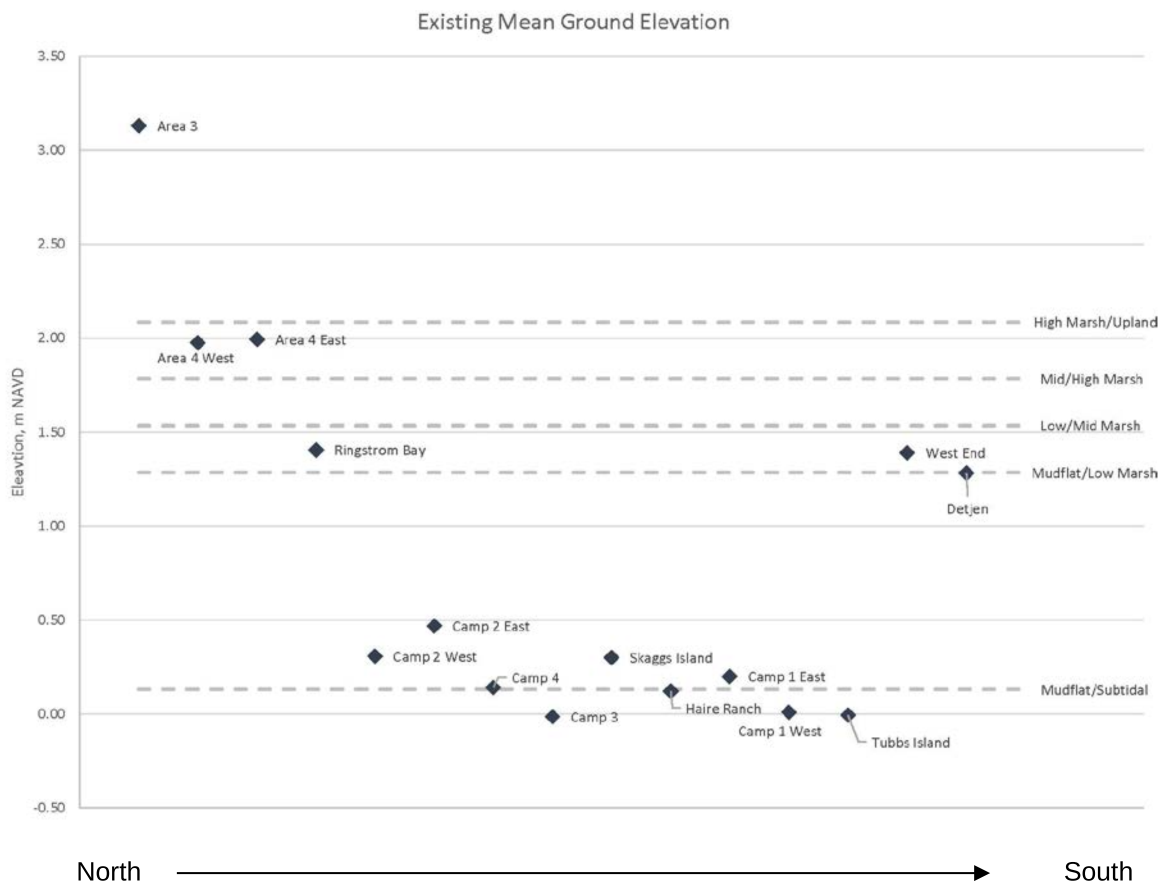

Figure 3. Existing mean ground elevations (data from Sonoma County Veg Map and CA OPC LiDAR-derived DEM).

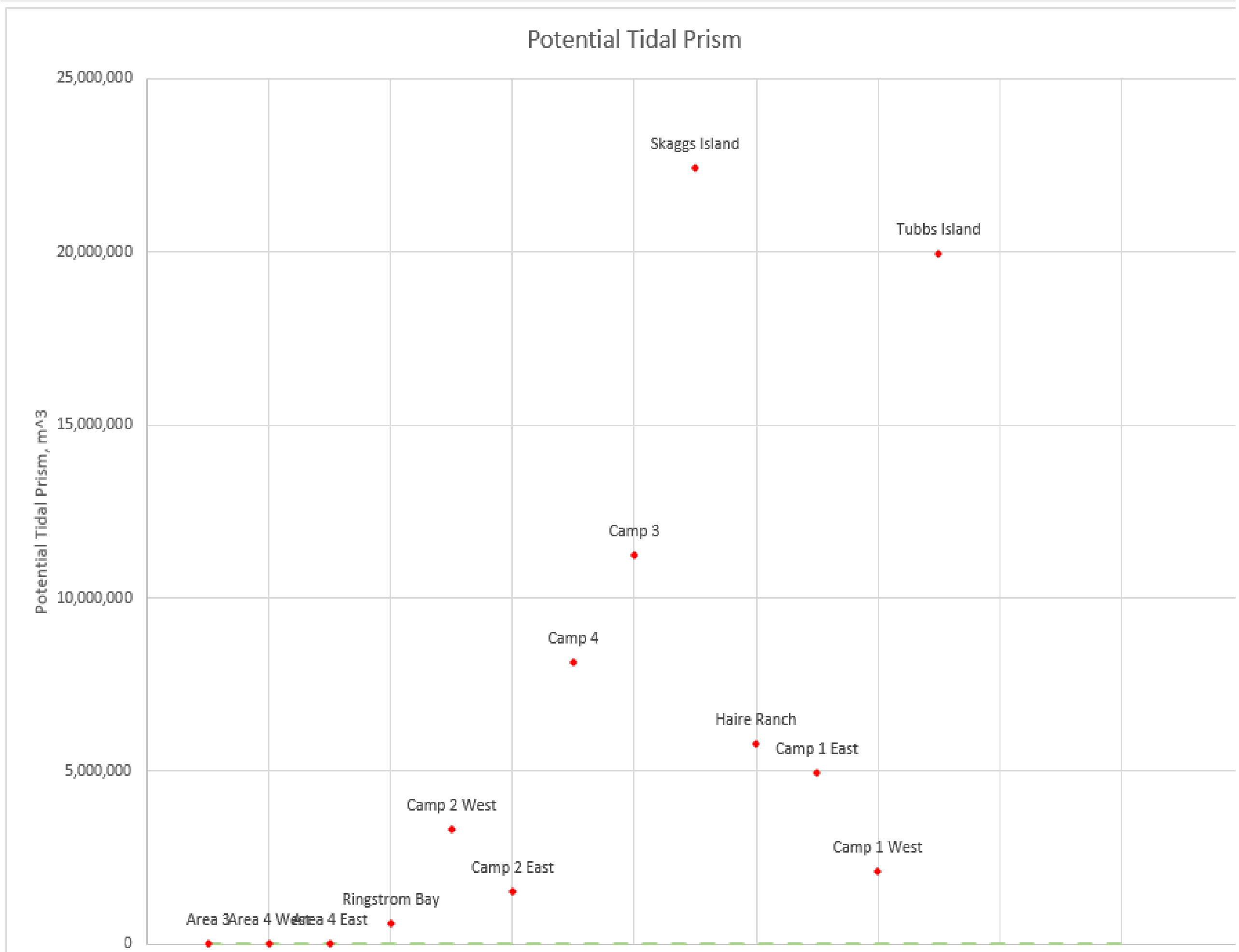

Figure 4. Potential tidal prisms of diked bayland, based on elevations from Sonoma County Veg Map and CA OPC LiDAR-derived DEM.

Historical Sonoma Creek

The historical width of Sonoma Creek prior to diking, measured from the earliest accurate surveys of these marshes taken in 1856 by the U.S. Coast and Geodetic Survey, was about 354m at the SR 37 bridge which corresponds to a tidal prism of approximately 25.2 million m^3 (Table 2). Subsequent diking and draining has reduced the channel at the bridge to its present width of about 118m for a tidal prism of about 2.0 million m^3.

Table 2. Historical, present, and potential Sonoma Creek width, depth, and cross-sectional area based on hydraulic geometry described in Williams et al. (2002).

	Historical	Present	Potential
Tidal Prism (Mm^3)	25.2	2.0	58.0
Width (m)	364	118	557
Depth (m)	7.9	4.9	9.1
Area (m^2)	1486	305	2694

In the future, an accidental breach on the east bank of the Sonoma Creek could inundate the whole of Skaggs Island including the former subtidal and mudflat areas. Such a breach at Skaggs Island could increase the tidal prism passing under the SR 37 bridge to as much as 21 million m^3 (more than it was historically due to the subsidence of former marshes) and increase the present width of 118m to about 357m. In the past, such breaches have been repaired relatively quickly, and the Sonoma Creek channel has not been significantly eroded. But in the future with rising sea levels, it may not be cost-effective to maintain these dikes, and the inundation could become permanent. In the extreme case, tidal action could be restored to all the former marshes either as planned marsh restoration projects or by accidental breaching. In this case, the maximum tidal prism of the Sonoma Creek is about 58 million m^3 giving a potential maximum width of about 557m. In addition to the channel to accommodate normal tidal flows, allowance would have to be made to maintain the adjacent creek marsh which at present is about 152m wide.

References

Williams, P. B., Orr, M. K., and Garrity, N. J. (2002). Hydraulic geometry: A geomorphic design tool for tidal marsh channel evolution in wetland restoration projects. *Restoration Ecology*, 10(3), 577–590.