**Supplemental Material**

## Text S1: Detailed GIS-based Methods

### Treatment and development of environmental variable GIS layers

We used a Digital Elevation Model (DEM) of Kauai (10 x 10 m resolution) obtained from the Hawaii Coastal Geology Group (www.soest.hawaii.edu/coasts) to generate a slope raster layer for the island using the 'Slope' Tool in ArcGIS 9.3.1 (ESRI, Redlands, CA). We then created an aspect raster layer from the DEM using the 'Aspect' Tool. Because aspect is a circular variable (ranging from 0°-360°), it was reclassified as two linear variables, northness (a gradient varying from south [-1] to north [1]) and eastness (a gradient varying from west [-1] to east [1]), using the 'Raster Calculator'. Northness = cosine (aspect in radians) and eastness = sine (aspect in radians); this allowed interpretable mean values to be calculated for each site (Roberts 1986; Guisan et al. 1999).

We developed a flow direction raster layer (which determines the direction water would flow) using the Kauai DEM and the 'Flow Direction' Tool and subsequently generated a flow accumulation raster from the flow direction layer using the 'Flow Accumulation' Tool. The flow accumulation raster layer was reclassified to produce a ridge layer (values = 0 flow accumulation were reclassified as 'ridges') and drainage layer (values ≥100 flow accumulation were reclassified as 'drainages'; i.e., pixels with ≥100 pixels flowing into them from higher elevations were considered drainages). This value of 100 was based on trials in which flow accumulation values reclassified as 'drainages' were varied and the resulting layers were placed over a DEM (Jenson and Domingue 1988) zoomed to a familiar abandoned Newell's shearwater breeding site to examine which values yielded the most realistic representation of drainages. The ridge and drainage layers were then used to generate two layers, one of distance to the nearest ridge and

one of distance to the nearest drainage (both based on three-dimensional surface area), using the 'Path Distance' Tool with the Kauai DEM as the 'input surface raster'. Maps of mean annual wind speed (m/s) at 30 m in altitude (200 x 200 m resolution; produced by AWS Truewind) were obtained from the Hawaii Statewide GIS Program (http://hawaii.gov/dbedt/ert/winddata/winddata.html).

A soil shapefile for Kauai was obtained from the USGS Soil Data Mart (http://soildatamart.nrcs.usda.gov/). Polygons of the same soil type were merged using the 'Merge' Function in 'Editor' and the shapefile was converted to a raster layer (10 x 10 m resolution) using the 'Feature to Raster' Tool. Using soil map unit information for Kauai available from the USGS Soil Data Mart, we reclassified soil type into a new variable: percent rock fragment composition within the soil from 0-76.2 cm soil depth; soils with a depth to bedrock of < 76.2 cm were characterized only from 0 cm to bedrock < 76.2 cm. To construct the layer of percent rock fragment composition, we developed two initial layers. First, we reclassified soils based on percent rock fragment composition as follows: no rock fragments = 0, no modifier before rock fragment size description (e.g., "stony" [15-35% fragment cover]) = 25, the modifier "very" (e.g., "very gravelly" [35-60% fragment cover]) = 50, the modifier "extremely" (e.g., "extremely cobbly" [60-90% fragment cover]) = 75 and exposed bedrock (assumed to be 100% rock cover) = 100. To account for more than one layer of soil with differing rock fragment compositions, we calculated the percent depth covered by the soil band(s) containing rocks between the surface and 76.2 cm depth (or between the surface and bedrock < 76.2 cm) and reclassified soil type based on these values. We then multiplied these two reclassified layers together to yield the general percent rock fragment composition within soil 0-76.2 cm in depth or from 0 cm to bedrock < 76.2 cm. Bedrock < 76.2 cm below the soil

surface was not factored into percent rock fragment cover because exposed bedrock is weathered and more likely to provide small-scale topographic features suitable for nesting (e.g., Brandt et al. 1995), whereas bedrock under the soil surface and unexposed to intense weathering may not. Only one soil type contained layers with rock fragments that differed in their modifier (i.e., they differed in overall percent rock composition); this was accounted for in the development of the percent rock fragment composition layer. Because our reclassification of Kauai soils was based on the typical profile for a soil map unit, minor soil components were not considered.

We used a preclassified land cover layer, a vegetation height layer and a vegetation canopy cover layer of Kauai (30 x 30 m resolution) from the Landscape Fire and Resource Management Planning Tools Project (www.landfire.gov) to develop three vegetation variables. The land cover layer was reclassified into native vegetation (= 1) and non-native vegetation and other land cover types (= 0) to create a native vegetation layer. Vegetation height was reclassified as an ordinal variable combining preclassified categories of height as follows: (a) open water, developed land and cultivated crops = NoData, (b) barren land = 0, (c) herb height 0->1 m, shrub height 0->3 m and forest height 0-5 m = 1, (d) forest height 5-10 m = 2 and (e) forest height > 10 m = 3. Combining height categories in this manner required the assumption that herbs above 1 m and shrubs above 3 m are less than 5 m in height. To create a woody vegetation canopy cover layer, we reclassified the vegetation canopy cover as follows: (a) open water, developed land and cultivated crops = NoData, (b) barren land and herb cover = 0 and (c) shrub and tree canopy cover into values from 2 to 10, such that >10-20% shrub or tree cover = 2, >20-30% = 3, etc.; no data were available for shrub or tree canopy cover in the 0-10% range.

All layers not projected in North American Datum (NAD) 1983 Zone 4 were converted to this projection using the 'Project' Tool. All reclassifications were performed using the

‘Reclassify’ Tool. All rasters not 10 x 10 m in resolution were converted to 10 x 10 m for analysis to generate mean predictor values for all variables based on identical pixel sizes.

**Habitat/threat-isolation index development**

Two threats to Newell’s shearwater are fledgling attraction to artificial light and close proximity to human disturbance. We combined GIS layers depicting these threats with our environmental variable model to develop habitat/threat-isolation index identifying regions predicted to contain structurally suitable habitat where fledglings would likely be less susceptible to artificial light attraction and less likely to experience the threats associated with human disturbance. For the artificial light threat, we used a GIS layer for the island of Kauai of the total intensity of artificial light a fledgling seabird could view if it traveled a least-cost path, based on topography, from any location on the island to 10 km past the coastline (Troy et al. 2011). For distance to nearest human disturbance, we developed a layer depicting distance to the nearest trail, road, developed land or agricultural land (based on three-dimensional surface area).

We obtained two USGS road shapefiles, one classified as ‘major roads’ and the second as ‘other roads’, for Kauai from the Hawaii Statewide GIS Program (http://hawaii.gov/dbedt/gis/). A buffer of 0.5 m surrounding all roads within each road layer was generated using the ‘Buffer’ Tool, transforming both road layers into a layer of merged road and trail polygons. We used the preclassified land cover layer of Kauai (30 x 30 m resolution) from the Landscape Fire and Resource Management Planning Tools Project (www.landfire.gov) to generate a polygon layer of developed and agricultural land by highlighting those land cover categories in the attributes table and using the ‘Raster to Polygon’ Tool to convert the highlighted land types to polygons (without polygon simplification). The developed and agricultural land and both trail and road polygon layers were merged using the ‘Merge’ Tool, and all individual polygons were then

93 merged using the ‘Merge’ Function in ‘Editor’. We used this shapefile to generate a raster layer
94 of distance to nearest road (10 x 10 m resolution), based on three-dimensional surface area, using
95 the ‘Path Distance’ Tool with the Kauai DEM as the ‘input surface raster’.
96 To combine these layers with our environmental variable model to develop the
97 habitat/threat-isolation index, we first reclassified the two threat layers into proportions by
98 dividing each layer by its highest pixel value using the ‘Raster Calculator’. Because greater
99 values of distance to the nearest terrestrial human disturbance may be associated with decreased
100 risk of threat to Newell’s shearwaters, we considered proportional values of this layer equivalent
101 to threat risk (on a scale from 0-1). Greater values of viewable artificial light, however, are likely
102 associated with greater risk that fledglings will be intercepted by light on their nocturnal fledging
103 flights. Therefore, we inverted the pixel values of the proportional night light layer so that the
104 highest values on the inverted map represented the lowest risk to fledglings and hence the lowest
105 threat. Both threat layers and the habitat suitability layer were then multiplied together using the
106 ‘Raster Calculator’ to produce a habitat/threat-isolation index layer accounting for these potential
107 threats. Each threat was equally weighted in production of the habitat/threat-isolation index.
108 We also developed an alternate version of this habitat/threat-isolation index in which the
109 layer representing the threat of introduced predator presence (described above) was weighted
110 three times higher than the layer representing the threat of fledgling attraction to artificial light
111 because previous authors estimated that introduced predators may have a greater negative effect
112 on the Newell’s shearwater population on Kauai (Ainley et al. 2001, Griesemer and Holmes
113 2011). For this calculation, a weight of 0.75 was applied to the layer for representing the threat of
114 introduced predator presence and a weight of 0.25 was applied to the layer representing the threat
115 of fledgling attraction to artificial light. These two layers were added together so that their total

weight summed to a value of one. This combined threat layer was then multiplied by the habitat suitability layer to produce the alternate habitat/threat-isolation index.

**Development of land ownership and designation layer**

A shapefile of large government and private landowners in the main Hawaiian Islands, holding at least 404.7 ha on an individual island (updated for Kauai in 2009), and a shapefile of designated habitat reserves (updated in 2011) were obtained from the Hawaii Statewide GIS Program (http://hawaii.gov/dbedt/gis/). We used the 'Create Layer From Selected Features' option in ArcGIS 9.3.1 (ESRI, Redlands, CA) to create both a large landowner and a reserve layer for Kauai from these layers. One copy of each layer was produced so that each copy of the same layer could be edited differently (using the 'Merge', 'Clip', and 'Explode' Functions in 'Editor') to create layers of different types. All government land polygons in the large landowner layer were merged into one group and all private land polygons were merged into another group using the 'Merge' Function. These government and private land polygons were then split into two separate layers using the 'Create Layer From Selected Features' option. We used the reserve layer to clip both the government and private land layers using the 'Clip' Function, and both the government and private land layers were then used to clip the reserve layer using the 'Clip' Function. This produced four individual landowner layers (government reserves, government non-reserves, private reserves, private non-reserves). For our analysis, we considered Limahuli Preserve (a privately owned reserve containing several Newell's shearwater activity sites) in northwestern Kauai as a reserve though the shapefile of reserves did not. Small remnant polygons along former boundaries of clipped polygons were deleted using the 'Explode' Function to separate all polygons in the layer and deleting them individually; the remaining

polygons were merged using the 'Merge' Function. These four landowner layers were merged using the 'Overlay' Tool.

The combination of these layers left portions of Kauai without landowner designation (i.e., non-reserve lands owned by those with < 404.7 ha). To fill these regions, we used a polygon of the boundary of Kauai obtained from the Hawaii Statewide GIS Program (http://hawaii.gov/dbedt/gis/). The merged four-landowner layer was then used to clip the island boundary layer to produce a layer of smaller landowners (which we termed 'other land') using the 'Clip' Function. Finally, this layer was combined with the four-landowner layer using the 'Overlay' Tool, yielding a layer with five land ownership categories (the four previously mentioned as well as 'other land').

## References


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