



## AGRICULTURAL COCONUT FOREST AS HABITAT FOR THE CRITICALLY ENDANGERED TUAMOTU KINGFISHER (*TODIRAMPHUS GAMBIERI GERTRUDAE*)

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**ABSTRACT.**—The effects of anthropogenic habitat modification are evident on tropical Pacific islands where forests have been extensively converted to plantations of Coconut Palm (*Cocos nucifera*). We evaluated resource selection in the critically endangered Tuamotu Kingfisher (*Todiramphus gambieri gertrudae*), which is confined to a single population on the low-elevation island of Niau Atoll in French Polynesia. Our analyses indicate that resources associated with foraging underlie space use and habitat selection of Tuamotu Kingfishers at multiple spatial scales. At the island scale, the occurrence of the species was best predicted by habitat features associated with foraging opportunities, including agricultural coconut forest with open understory, hunting perches, and exposed ground. Conversely, the species' distribution was negatively associated with undisturbed vegetation, including primary feo forest and fallow coconut plantation. At the home-range scale, utilization distributions of radiomarked Tuamotu Kingfishers also indicated that birds selected agricultural coconut forest and least preferred native feo forest. Observations further indicated that foraging birds selected coconut plantations managed with prescribed burning for hunting. The Tuamotu Kingfisher is a rare example of a threatened tropical species that likely benefits from agricultural management, and our findings provide support for conservation strategies based on establishing rescue populations on other islands with coconut plantations. We suggest that incorporating agricultural coconut forests into conservation planning could help prevent the extinction of several kingfisher species that historically relied on the natural broadleaf habitats that are now almost entirely absent from insular Pacific Oceania. Received 13 August 2010, accepted 22 February 2011.

Key words: coconut agriculture, foraging habitat, Pacific islands, prescribed burning, resource selection, *Todiramphus gambieri*, Tuamotu Kingfisher.

### Les plantations de cocotiers comme habitat d'une espèce en danger critique d'extinction, *Todiramphus gambieri gertrudae*

**RÉSUMÉ.**—Les effets de la modification anthropique de l'habitat sont évidents sur les îles tropicales du Pacifique où les forêts ont été extensivement converties en plantations de *Cocos nucifera*. Nous avons évalué la sélection des ressources chez *Todiramphus gambieri gertrudae*, une espèce en danger critique d'extinction limitée à une seule population sur l'île à basse altitude de Niau Atoll, en Polynésie française. Nos analyses indiquent que les ressources associées à la quête de nourriture sont à la base de l'utilisation de l'espace et de la sélection de l'habitat par cette espèce à plusieurs échelles spatiales. À l'échelle de l'île, les caractéristiques de l'habitat associées à des opportunités d'alimentation, telles que les plantations de cocotiers avec un sous-étage ouvert, des perchoirs de chasse et un sol exposé, sont les facteurs qui permettent le mieux de prédire la présence de l'espèce. À l'inverse, la répartition de l'espèce était négativement associée à une végétation non perturbée, telle que les forêts primaires et les plantations de cocotiers en jachère. À l'échelle du domaine vital, la répartition des individus munis d'émetteurs a également indiqué que les oiseaux ont sélectionné les forêts agricoles de cocotiers et ont moins préféré les forêts primaires. Les observations ont de plus indiqué que les oiseaux en quête alimentaire ont sélectionné les plantations de cocotiers gérées à l'aide du brûlage dirigé pour la chasse. *T. gambieri gertrudae* constitue un exemple rare d'une espèce tropicale menacée susceptible de bénéficier de la gestion agricole. Nos résultats soutiennent les stratégies de conservation basées sur l'établissement de populations de sauvetage sur d'autres îles possédant des plantations de cocotiers. Nous suggérons que le fait d'incorporer les forêts agricoles de cocotiers dans la planification de la conservation peut aider à prévenir l'extinction de plusieurs espèces de martins-pêcheurs qui dépendaient par le passé des habitats naturels de feuillus qui sont désormais pratiquement absents des îles d'Océanie, dans le Pacifique.

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ISLAND BIRDS ACCOUNT for 90% of human-caused avian extinctions, and the trend will likely continue, given that Pacific islands currently host the greatest number of threatened species (Johnson and Stattersfield 1990). In French Polynesia, for example, 18 of 25 endemic landbird species are threatened with extinction (Gouni and Zysman 2007). Threats are based on human activity and include introduced species, habitat loss, and hunting (Milberg and Tyrberg 1993, Steadman 1997, Blackburn et al. 2004).

Anthropogenic habitat modification poses great risks for island fauna (Steadman 1997, BirdLife International 2000), and it affects >90% of threatened birds worldwide (BirdLife International 2010a). Habitat loss was included in Diamond's (1984) "evil quartet" of factors causing extinction and Wilson's (2002) "HIPPO" list of threats to biodiversity. Some suggest that loss of avian habitat is occurring primarily through the expansion and intensification of agriculture and the conversion of tropical forest to agriculture (Jetz et al. 2007). On islands, most threatened landbirds inhabit forests (Johnson and Stattersfield 1990), and many island forests have already been degraded or destroyed (Fordham and Brook 2010). For example, lowland forests on numerous Pacific islands have been converted to agricultural Coconut Palm (*Cocos nucifera*) plantations (Mueller-Dombois and Fosberg 1998). Conservation thus requires the identification and preservation of key forested habitats and a greater understanding of how birds use and interact with modified landscapes (Chazdon et al. 2009).

Conservation managers can attempt to reintroduce species to areas where they have been extirpated or conduct releases outside the known historical range when limited native habitat remains (IUCN 1987, 1998). There have been concerns about using translocation as a conservation tool and about the risks to recipient ecosystems (Armstrong and Seddon 2008). However, translocation can be a viable rescue strategy and may provide one of the only methods for preserving avian diversity on Pacific islands (Seitre and Seitre 1992, Steadman 2006). Translocation may be simpler on oceanic islands than on continents because islands tend to host fewer species and, thus, competition and predation pressures

are likely reduced. For example, only two or three landbird species are found on most islands in the French Polynesian Tuamotu archipelago. Additionally, habitat features are shared among islands and across wide regions (Whittaker and Fernandez-Palacios 2007). Even in these simple systems, however, careful consideration must be given to selecting potential release sites with high-quality habitats (Wolf et al. 1998).

The Tuamotu Kingfisher (*Todiramphus gambieri gertrudae*) is among the most threatened birds in the world, with only one extant population of ~125 individuals (BirdLife International 2010b). As is the case for many threatened tropical species, information about the natural history and ecological requirements of the Tuamotu Kingfisher is almost nonexistent. The nominate subspecies (*T. g. gambieri*) was extirpated from the Gambier Islands in the late 19th century (Holyoak and Thibault 1984), and the species is now confined to the small atoll island of Niau, where tropical forest has been extensively converted to coconut agriculture (Butaud 2007). Introduced rats (*Rattus exulans* and *R. rattus*) and cats (*Felis catus*) may also affect the Tuamotu Kingfisher population through predation and competition for food (Townsend et al. 2006, Buckley and Jetz 2007). Additionally, the Tuamotu Kingfisher population may have been adversely affected by a series of destructive cyclones (Dupon 1986).

We studied Tuamotu Kingfishers at the island, home-range, and foraging scales (Johnson 1980, Block and Brennan 1993) to identify resources associated with the species' survival and reproduction and to provide information for the conservation management of the birds on Niau. We also intend the results of our study to inform conservation practitioners who are evaluating islands for the potential establishment of a second Tuamotu Kingfisher population through translocation (Gouni et al. 2006).

## METHODS

*Study site.*—Niau Atoll (16°10'S, 146°22'W; Fig. 1) is part of the Tuamotu Archipelago Endemic Bird Area (EBA 214; BirdLife

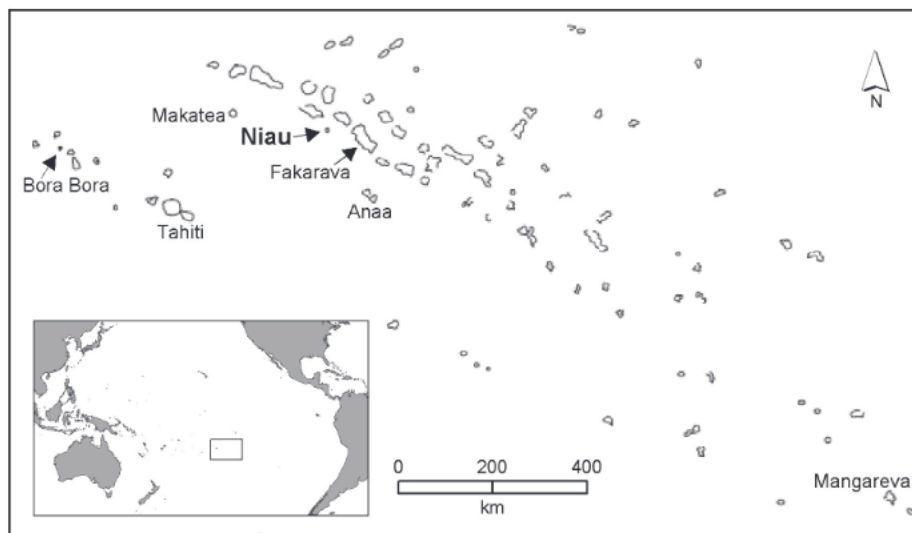


FIG. 1. Location of Niau Atoll in the Tuamotu archipelago in French Polynesia.

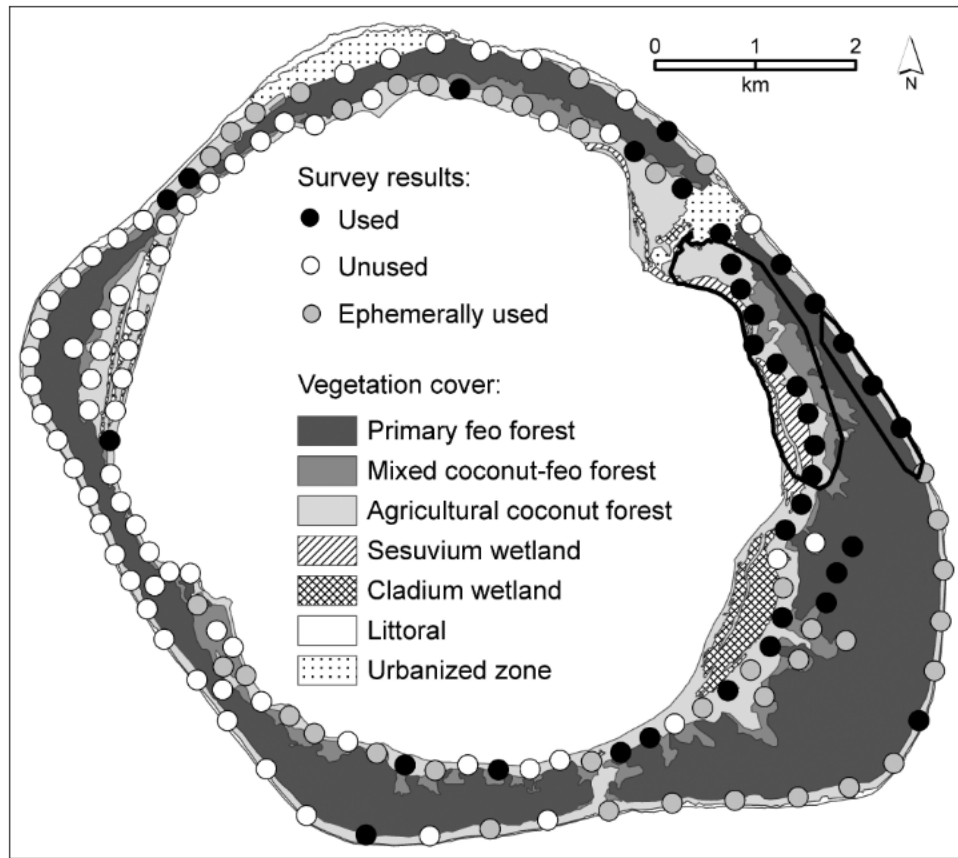


FIG. 2. Vegetation cover map of Niau Atoll, adapted with permission from Butaud (2007). Locations and results of Tuamotu Kingfisher surveys conducted in 2006–2008 are depicted as dots, and home-range-scale study areas are encircled.

International 2003) and the UNESCO Man and Biosphere Reserve of Fakarava in French Polynesia. Niau is a low island with an elevation of 5–8 m above sea level, a land area of 26 km<sup>2</sup>, and a large enclosed lagoon (Andréfouët et al. 2005). Production of coconut pulp (copra) underpins Niau's economy, and agricultural coconut forests occur along the lagoon and ocean shores (Fig. 2). Coconut plantations range from fallow plots with dense understory vegetation to heavily managed plots with exposed ground. Wetlands dominated by Shoreline Purslane (*Sesuvium portulacastrum*) and Jamaica Swamp Sawgrass (*Cladium mariscus*) (Butaud 2007) occur on the eastern fringe of the lagoon. The littoral zone along the ocean shore consists of coral reef with low strand vegetation and sparse coconut trees. Inland areas are characterized by dense primary forest growing on jagged fossilized limestone coral (feo forest). Mixed coconut–feo forest occurs on the interior edge of the feo forest. The climate is tropical oceanic without pronounced seasons, with a mean annual temperature of 26°C and annual rainfall of 1,500–2,000 mm (Mueller-Dombois and Fosberg 1998).

#### Island-scale Resource Selection

We used an information-theoretic approach (Burnham and Anderson 2002) to evaluate the association between island-scale resources and the spatial distribution of Tuamotu Kingfishers. We developed four *a priori* logistic regression models that relate the probability of

occurrence of Tuamotu Kingfishers to nesting resources, foraging habitat, undisturbed vegetation, or a combination of these factors (Table 1). Tuamotu Kingfishers nest in standing dead trees (hereafter “snags”), and the population may thus be limited by the number of available nest sites (Newton 1994). We also considered foraging habitat, which potentially limits population size in birds (Martin 1987, Newton 1998). Open habitat, hunting perches, and exposed ground are used for foraging by Tuamotu Kingfishers, which are opportunistic sit-and-wait predators of lizards and a wide variety of small arthropods (Marie 2006). Our third model predicted that Tuamotu Kingfisher occurrence was negatively affected by human disturbance and modified vegetation in agricultural coconut forest (Block and Brennan 1993).

*Tuamotu Kingfisher surveys.*—We surveyed Niau Atoll for Tuamotu Kingfishers at 145 stations in February 2006, November 2007, and November 2008. We used a handheld global positioning system (GPS; Rino 520HCx; Garmin, Olathe, Kansas) to establish systematically spaced survey stations. The stations encircled the island on the lagoon and ocean sides, and they were spaced at 300-m intervals, except on the eastern ocean coast, where they were spaced at 500-m intervals because of extensive stretches of uniform habitat (Fig. 2). We conducted surveys between 0500 and 0900 hours during clement weather (wind <20 km h<sup>-1</sup> and no rain). We broadcast Tuamotu Kingfisher calls through handheld

TABLE 1. Ranked logistic regression models of the probability of Tuamotu Kingfisher occurrence on Niau Atoll;  $\pi$  is the predicted probability of Tuamotu Kingfisher occurrence,  $k$  is the number of parameters,  $AIC_c$  is second-order Akaike's information criterion,  $w_i$  is Akaike weight (i.e., model probability given the set of candidate models), and MC is managed coconut forest.

Model	Model structure: $\text{logit}(\pi) = \beta_0 + \dots$	Log likelihood	$k$	$AIC_c$	$\Delta AIC_c$	$w_i$
Foraging opportunities	$\beta_1(\text{MC}) + \beta_2(\text{mean perch distance}) + \beta_3(\text{exposed ground}) + \beta_4(\text{wetland})$	-30.55	5	72.27	0.00	0.854
Undisturbed vegetation	$\beta_1(\text{high vegetation}) + \beta_2(\text{MC}) + \beta_3(\text{non-agricultural forest})$	-33.84	4	76.45	4.18	0.116
Global	(includes all variables)	-30.15	8	79.30	7.03	0.025
Null	(includes the intercept only)	-39.50	1	81.07	8.80	0.010
Nest sites	$\beta_1(\text{snag density})$	-39.28	2	82.79	10.52	0.004

speakers for 60 s and recorded audio and visual detections of Tuamotu Kingfishers during the subsequent 10 min. Based on previous behavioral observations in areas where Tuamotu Kingfishers were known to occur, we assumed that birds within  $\leq 100$  m responded to the playback calls. Tuamotu Kingfishers are aggressive territorial residents and are highly site-faithful (Coulombe 2010). Thus, we assumed that detections represented birds that were using resources near survey stations.

For vegetation analysis and statistical modeling, we employed a conservative approach and selected a subset of our survey stations with strong indications of Tuamotu Kingfisher use or absence. We considered stations unused if individuals were never detected ( $n = 73$ ), and used if individuals were detected in 2008 and at least one other year ( $n = 36$ ). Other stations were considered ephemerally used ( $n = 36$ ) and were not included in the analysis. Tuamotu Kingfishers are entirely terrestrial, so stations were excluded if  $>25\%$  of the area within a 100-m radius was water (lagoon or ocean;  $n = 24$ ). Areas surrounding remaining stations had a mean of  $<6\%$  water. Logistical constraints prevented measurement of resources at some stations, so we randomly selected 28 used stations and 29 unused stations for site surveys and inclusion in our modeling.

**Resources.**—We evaluated resources within 100 m of each survey station (Fig. 3). We selected a 100-m radius because preliminary work suggested that birds responded to playback calls from a similar distance and because the encompassed area (3.1 ha) is approximately half the size of a Tuamotu Kingfisher territory (Coulombe 2010). We used a land-cover map of Niau (Butaud 2007) and a geographic information system (GIS; ARCGIS, version 9.3; ESRI, Redlands, California) to measure the proportional composition of vegetation types (agricultural coconut forest, mixed coconut-feo forest, primary feo forest, and wetland) included in the 3.1 ha of each sampling site. We categorized agricultural coconut forest within the 3.1 ha surrounding each survey station as managed or fallow, depending on whether the area was actively used to produce coconuts.

We also surveyed nest snags, ground cover, and hunting perches at each site. For the site measurements, we used 200-m-long linear transects oriented in the observer transit direction and centered on Tuamotu Kingfisher survey stations (Fig. 3). We used previous observations to define potential nest snags as dead coconut trees  $>1.25$  m tall and with sufficient decomposition to have lost the tree crown. We recorded the distance to the nearest snag from four locations ( $-75$ ,  $-25$ ,  $25$ , and  $75$  m) along each transect. Snag density was then estimated for each site ( $1/[4 * (\text{mean distance})^2]$ ; Waite

2000). We sampled ground cover using six  $10 \times 10$  m quadrats established on each side of the linear transect ( $-50$ ,  $0$ , and  $50$  m) and halfway to the feo forest or water edge (measured with laser range finder; Bushnell Yardage Pro Sport 450). In each quadrat, we visually estimated the proportion of exposed ground (vegetation  $<50$  cm tall) and high vegetation ( $>50$  cm tall) and then multiplied the mean results by the area of coconut forest within the 3.1-ha sampling site to extend our estimates to the sampling site. We measured the distance to potential hunting perches at two locations ( $-50$  and  $50$  m) along each transect. Hunting perches were defined

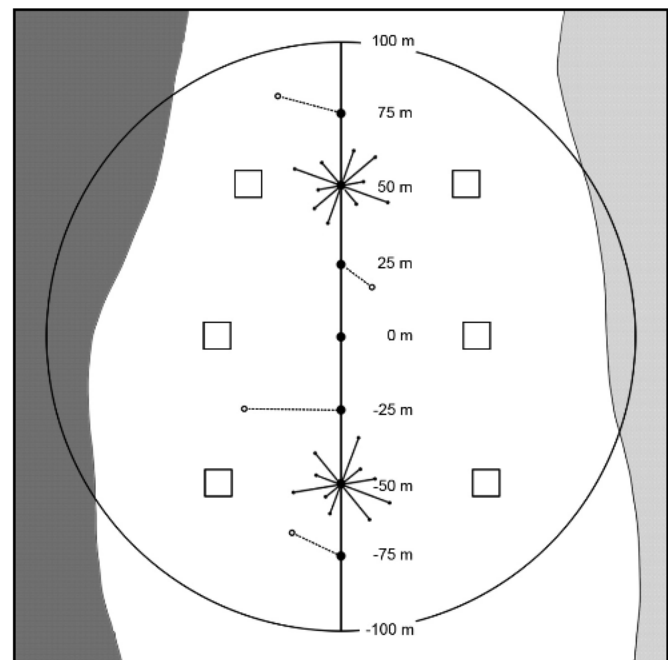


FIG. 3. Transect and quadrat configuration for assessing resources on sampling sites of 3.1 ha and centered on Tuamotu Kingfisher survey stations (0 m along transect). We used the GIS to evaluate habitat coverage within 100 m of the survey station. During site visits, we surveyed snags at  $-75$ ,  $-25$ ,  $25$ , and  $75$  m (e.g., unfilled points); ground cover between transect and halfway to the feo forest or water edge at  $-50$ ,  $0$ , and  $50$  m (boxes); and hunting perches in 10 predefined orientations at  $-50$  and  $50$  m along the transect.

by branches 1.6 m above the ground (eye-level and approximate perching height for hunting). We used a floating compass (Suunto KB-20, Vantaa, Finland) and the laser range finder to measure the distance to the nearest perch in 10 directions, each separated by 30°. If no perches were present before the water edge (lagoon or ocean), we entered a surrogate value of 200 m. Perch distances were averaged for each sampling site; a shorter mean distance indicated higher perch density.

**Model selection.**—We used Program R (glm function; R Development Core Team 2009) to compute the maximum-likelihood parameter estimates (MLE) and deviance ( $-2 \log$  likelihood) of our candidate models. We ranked candidate models on the basis of a second-order Akaike's information criterion ( $AIC_c$ ; Burnham and Anderson 2002) and tested model fit with a Hosmer-Lemeshow goodness-of-fit test (Hosmer and Lemeshow 2000). We explored simpler versions of our top-ranked models by removing variables with insignificant parameter estimates (95% confidence intervals [CIs] overlapping zero) or variables that might not explain enough variation to be included in a final model. We then ranked our original and post hoc models on the basis of  $AIC_c$  values.

### Home-range-scale Resource Selection

Our two study areas were situated on the east side of Niau, between the feo forest and the lagoon (152 ha) and between the feo forest and the ocean (39 ha; Fig. 2). We tested whether birds used habitats disproportionately to the amount available (Johnson 1980, Jones 2001, Buskirk and Millspaugh 2006). We radiotracked Tuamotu Kingfishers to model space use within home ranges, and we compared the intensity of habitat use to habitat availability within study areas (design 2, *sensu* Thomas and Taylor 2006). We considered a home range to be the area used by a bird during its regular daily movements in a single breeding season.

**Radiotelemetry.**—Radiotracking was conducted during the Tuamotu Kingfisher breeding season in October–November 2006, October–November 2007, and September–December 2008. We thoroughly searched the study areas to find all individuals and nests. We attempted to capture all birds on the study areas with mist nets, or with a hoop net at the nest cavity, following the initiation of incubation. Birds were marked with numbered aluminum leg bands and unique combinations of colored darvic leg bands and were fitted with radiotransmitters (model BD-2; Holohil Systems, Ottawa, Ontario) weighing 1.5 g ( $\leq 4\%$  of body mass; Gaunt et al. 1999) and with an average life span of 8 weeks. We used a modified leg harness designed to allow transmitters to be shed from birds after the conclusion of field work (Kesler 2011). Previous analyses showed no transmitter effects on behavior or survival of Tuamotu Kingfishers (Kesler 2011). We collected a small blood sample from the brachial vein and used primers P2/P8 for molecular sex determination (Kesler et al. 2006).

We located radiotagged birds throughout daylight hours (between 0500 and 1800 hours) because previous investigations of a congener found that nocturnal movements were unlikely (Kesler and Haig 2007c). Birds were located approximately twice daily, with consecutive sampling separated by  $>2$  h to avoid serial correlation (Kesler and Haig 2007b). We located birds using a handheld Yagi antenna and telemetry receiver (model R-1000; Communications Specialists, Orange, California) and recorded geographic coordinates with a GPS.

When we could not observe birds visually, we used a compass and triangulation to estimate locations. Consecutive directional bearings were separated by  $<10$  min to minimize error from bird movement. We estimated the maximum-likelihood location for each bearing group using LOAS (Ecological Software Solutions, Urnäsch, Switzerland). We excluded triangulations that had a 95% error ellipse  $>0.6$  ha, which was  $\sim 10\%$  of the mean Tuamotu Kingfisher territory (Coulombe 2010). We excluded relocation points within 10 m of nests to eliminate cluster bias on kernel density results (White and Garrott 1990).

**Habitat use versus availability.**—We derived utilization distributions (UDs) from the telemetry-based bird locations to define habitat use. The UD provides a probabilistic measure of space use and reduces concerns about independence of points and error related to telemetry and mapping (Marzluff et al. 2004, Thomas and Taylor 2006). We derived the UD using KernelHR (version 4.27; Seaman et al. 1998) with a fixed kernel-density estimator and bandwidth selection based on least-square cross-validation (Seaman and Powell 1996). Individual Tuamotu Kingfisher home ranges often shift from year to year, and one mate usually attends to the nest while the other moves about. Thus, separate UD were derived for each home range. We separated data for birds retagged during a subsequent season ( $n = 5$ ) and birds in tagged pairs ( $n = 8$ ). We derived 28 UD from 23 individual birds (15 males and 13 females), which represented  $\sim 18\%$  of the extant population. These included 9, 12, and 7 UD from 2006, 2007, and 2008, respectively.

We overlaid the UD grids on a vegetation-cover map of Niau (Butaud 2007) with the GIS. We included 95% of the UD by volume to reduce potential bias from the tails and measured the proportion composed of each habitat type. Habitat availability in each study area was defined with a minimum convex polygon representing the maximum extent of where radiomarked Tuamotu Kingfishers were located. We derived the polygons from the telemetry location points using ET GeoWizards (Tchoukanski 2009) and measured the proportional area of each habitat type in GIS. We excluded areas covered by the lagoon, ocean, and urbanized zone.

We used a weighted compositional analysis (multivariate analysis of variance; Aebischer et al. 1993, Millspaugh et al. 2006) in Resource Selection for Windows (Leban 1999) to assess resource selection within each study area. We report when birds used habitats in disproportion to availability, and we rank habitats from most to least preferred. We pooled home-range data from males and females and from all years (2006–2008) because there was no sex or year effect on space use (Coulombe 2010). Compositional analysis has been criticized for inflating Type I error rates from rare habitat types with zero use values (Bingham et al. 2007). However, in this case the method was robust, because availability was  $\geq 5\%$  for all habitat types. Further, to ensure consistency in the ranking results, the analyses were completed twice, first replacing zero use values with 0.01 as recommended by Aebischer et al. (1993), and then with 0.3–0.7 as recommended by Bingham and Brennan (2004); rankings were equivalent. We used  $\alpha < 0.05$  to establish significance.

### Focal Foraging Observations

We conducted 1-h focal watches ( $n = 31$ ) on four Tuamotu Kingfisher territories where a parent was radiomarked in September–November 2008. Three territories were situated within the larger

TABLE 2. Ranked simplified post hoc logistic regression models of the probability of Tuamotu Kingfisher occurrence on Niau Atoll;  $k$  is the number of parameters,  $AIC_c$  is second-order Akaike's information criterion,  $w_i$  is Akaike weight, and MC is managed coconut forest.

Model	Variables	Log likelihood	$k$	$AIC_c$	$\Delta AIC_c$	$w_i$
Post hoc 1	MC + mean perch distance + exposed ground	-30.62	4	70.02	0.00	0.641
Foraging opportunities	MC + mean perch distance + exposed ground + wetland	-30.55	5	72.27	2.25	0.208
Post hoc 3	MC + exposed ground	-34.16	3	74.78	4.76	0.059
Post hoc 2	MC + mean perch distance	-34.38	3	75.22	5.20	0.048
Post hoc 4	MC	-35.7	2	75.80	5.78	0.036
Null	(intercept only)	-39.50	1	81.07	11.06	0.003

lagoon study area, and they were separated by at least three other territories; the fourth territory was situated within the smaller ocean study area. We observed all nests that were active during the field work, and each territory encompassed all of the major habitat types from the associated study area. Focal watches were conducted by two observers. One observer tracked the radiomarked bird and recorded habitat and substrate used during foraging. The second observer waited behind a blind at the nest to verify that prey items captured by the radiomarked birds were used for nest provisioning. The data provided proportional foraging habitat use and the habitats used for nest provisioning. Observers also recorded provisioning activities from the second parent when it also delivered items to the nest.

## RESULTS

*Island-scale resource selection.*—Tuamotu Kingfishers were detected at 26%, 21%, and 27% of survey locations in 2006, 2007, and 2008, respectively. We classified 36 stations (25%) as used by Tuamotu Kingfishers and 73 stations (50%) as unused (Fig. 2). The birds were most common on the eastern portion of the island. All stations near *Sesuvium*-dominated wetlands were used. Several used stations were situated within primary feo forest, but they were within 100 m of small patches of managed coconut plantations.

The foraging model ranked well above all other models of Tuamotu Kingfisher occurrence on Niau (Akaike weight [ $w_i$ ] = 0.854; Table 1). Further, the foraging model was a good fit for the data (i.e., predicted values did not significantly differ from observed values;  $\chi^2 = 8.138$ ,  $df = 8$ ,  $P = 0.420$ ). The model of undisturbed vegetation ranked second ( $w_i = 0.116$ ), and it too was a reasonable fit ( $\chi^2 = 10.422$ ,  $df = 8$ ,  $P = 0.237$ ). Interestingly, parameter estimates indicated a relationship opposite of that expected: Tuamotu Kingfishers were less likely to occur in undisturbed vegetation. However, the vegetation model was considerably less plausible when compared with the foraging model ( $\Delta AIC_c = 4.18$ ). Snag density was unlikely to influence Tuamotu Kingfisher distribution on Niau ( $\Delta AIC_c = 10.22$ ;  $w_i = 0.004$ ). We explored simpler post hoc versions of the top-ranked foraging model and found that the model performed better when we excluded wetland (Table 2). The best-performing post hoc model was represented by the logistic equation  $\text{logit}(\pi) = -1.882 + 2.380(\text{managed coconut forest}) - 0.076(\text{mean distance to perch in m}) + 0.062(\% \text{ exposed ground})$ , where  $\pi$  is the predicted probability of Tuamotu Kingfisher occurrence and

managed coconut forest is a categorical variable. Coconut forests were managed on 82% of the sampling sites used by Tuamotu Kingfishers and 48% of the unused sites. Mean ( $\pm$  SD) perch distance was  $29.6 \pm 10.7$  m on used sites and  $30.9 \pm 15.7$  m on unused sites. On used sites, there was  $1.5 \pm 0.5$  ha of exposed ground, whereas unused sites included  $1.2 \pm 0.5$  ha of exposed ground. Tuamotu Kingfisher occurrence was significantly associated with all three explanatory variables: parameter estimates ( $\pm$  SE) were  $2.380 \pm 0.795$  ( $P = 0.014$ ) for managed coconut forest,  $-0.076 \pm 0.032$  ( $P = 0.017$ ) for mean distance to perch, and  $0.062 \pm 0.025$  ( $P = 0.003$ ) for percentage of the area that was exposed ground. With other variables held at their mean, the model predicted that the probability of Tuamotu Kingfisher occurrence increased from 18% in fallow coconut forest to 70% in managed coconut forest. Parameter estimates also indicated increased probability of Tuamotu Kingfisher occurrence with a shorter mean distance to hunting perch and with increased exposed ground (Fig. 4).

*Home-range-scale resource selection.*—We obtained telemetry locations (Fig. 5) from visual observations (87%), triangulation (10%; median error ellipse: 0.06 ha), and biangulation (3%). We generated 28 UD home ranges (e.g., Fig. 5) with a mean of  $34 \pm 9$  (SD) telemetry locations. One UD was excluded from the study because it was based on <15 observations. Home-range size, as defined by the 95% volume kernel density isopleths, averaged 4.2 ha (geometric mean; 95% CI: 3.0–5.9 ha). Home ranges were composed primarily of agricultural coconut forest, which accounted for 39–88% of the area used by birds and 54–93% of the intensity of use (Table 3).

Tuamotu Kingfishers from both study areas selected habitats in proportions that differed from availability (lagoon:  $\chi^2 = 42.4$ ,  $df = 3$ ,  $P < 0.0001$ ; ocean:  $\chi^2 = 29.7$ ,  $df = 2$ ,  $P < 0.0001$ ). Within the lagoon study area, agricultural coconut forest ranked first, followed by wetland, mixed coconut–feo forest, and primary feo forest. Within the ocean study area, agricultural coconut forest ranked first, the littoral zone ranked second, and primary feo forest ranked last. Results of the weighted compositional analysis indicated that agricultural coconut forest was preferred over other types of habitats in both study areas ( $P < 0.05$  for both). Further, wetland was used more than mixed coconut–feo forest and primary feo forest within the lagoon study area ( $P < 0.05$ ), and the littoral zone was used significantly more than feo forest within the ocean study area ( $P < 0.05$ ).

*Focal foraging observations.*—Results of focal watches further supported the utility of managed agricultural coconut forest for

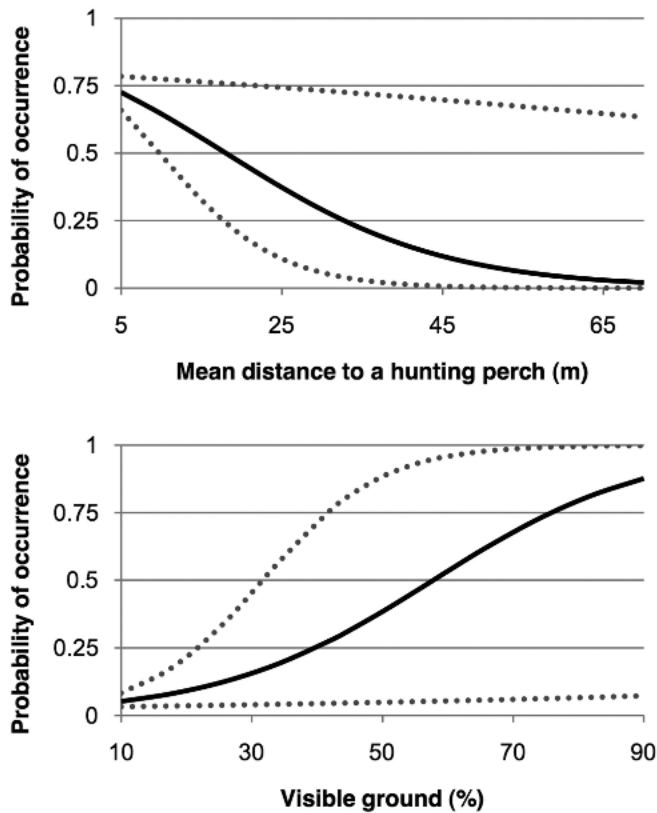


FIG. 4. Predicted effect of the mean distance to hunting perch (top) and of the proportion of exposed ground (bottom) on the probability of Tuamotu Kingfisher occurrence; dotted lines illustrate 95% confidence interval.

the Tuamotu Kingfisher. During focal watches, we observed 168 Tuamotu Kingfisher foraging events, 46% of which were confirmed successful, 40% assumed successful, and 14% assumed failed. Successful attempts ( $n = 143$  observations) occurred in managed coconut forest (78%), fallow coconut forest (10%), wetland (11%), and fallow coconut forest or primary feo forest (1%). Foraging substrate was exposed ground (62%), tree leaf (10%), tree trunk (8%), low vegetation (3%), and unknown (17%). Items acquired in wetlands (15 events) were comparatively smaller, and none were provisioned to nestlings. Food items provisioned to nestlings by radiomarked

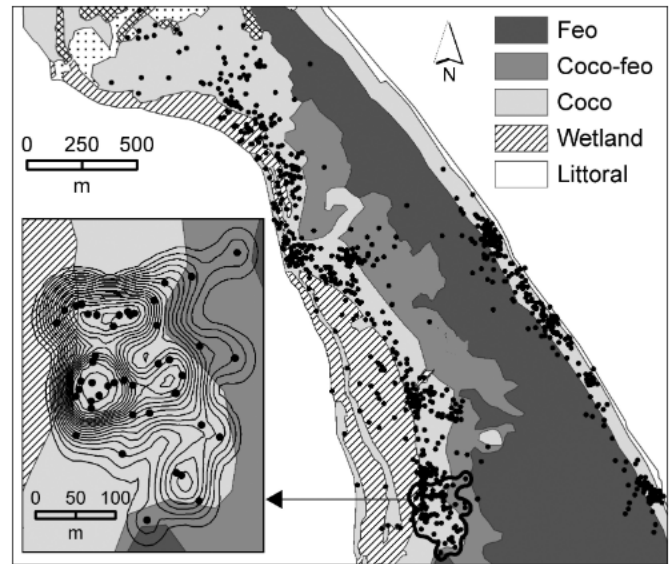


FIG. 5. Radiotelemetry locations (dots) of Tuamotu Kingfishers on Niau Atoll in 2006–2008. Inset is an example of a Tuamotu Kingfisher home range bounded by the 95% kernel utilization distribution isopleths. Internal contours represent kernel-density predicted intensity of use of areas within the home range.

Tuamotu Kingfishers ( $n = 23$  observations) were acquired in managed coconut forest (74%), fallow coconut forest (13%), fallow coconut forest or primary feo forest (9%), and unknown (4%). The foraging substrates from which items were obtained for provisioning nestlings were exposed ground (26%), tree leaf (17%), tree trunk (9%), low vegetation (4%), and unknown (43%).

DISCUSSION

Tuamotu Kingfishers selected agricultural coconut forest over indigenous feo forest habitats. This pattern was evident at the island level, within home ranges, and during foraging. Further, the birds preferred managed coconut forest over fallow coconut forest. Indeed, some of the most intensively managed plantations on Niau hosted successful breeding pairs of Tuamotu Kingfishers. On Niau, prescribed fire is used as an agricultural tool. In other

TABLE 3. Distribution of habitat types within two study areas on Niau Atoll and mean proportion within Tuamotu Kingfisher home ranges in 2006–2008. Home-range areas were defined using the 95% utilization distribution (UD) isopleth. The UD represents the intensity of use by Tuamotu Kingfishers. Value ranges are given in parentheses.

	Agricultural coconut forest		Wetland		Littoral zone		Mixed coconut–feo forest		Primary feo forest	
	Lagoon	Ocean	Lagoon	Ocean	Lagoon	Ocean	Lagoon	Ocean	Lagoon	Ocean
Availability within study areas (%)	44	35	25	0	0	5	23	0	8	60
Mean area within home ranges (%)	65 (39–88)	65 (41–85)	24 (6–55)	0	0	7 (0–16)	10 (0–35)	0	2 (0–8)	28 (8–55)
Mean UD (%)	72 (54–93)	78 (66–84)	20 (3–43)	0	0	7 (0–16)	7 (0–30)	0	1 (0–4)	15 (6–31)

lowland tropical forest systems, agricultural fire likely caused avian extinctions (Olson and James 1982). However, Niau farmers only occasionally burn, and when fire is used it is applied to small piles of woody debris so that fires do not propagate. Because fires expose ground, Tuamotu Kingfishers often foraged in burned sites, and managed coconut plantations may thus provide more foraging opportunities than fallow plantations and primary feo forest. Our results also suggested that foraging resources underpinned Tuamotu Kingfisher space use and resource selection on Niau. Island-scale distribution of the species was best explained by features associated with foraging, including open understory, hunting perches, and exposed ground. Home-range-scale results illustrated disproportionate use of coconut and wetland habitats where Tuamotu Kingfishers were commonly observed hunting arthropods and lizards (Scincidae and Gekkonidae; Ineich et al. 2007). Further, birds that had access to primary feo forest or fallow coconut forest within their home ranges selected managed areas of coconut forest for hunting prey to provision nestlings.

The apparent utility of coconut forest for Tuamotu Kingfishers, and the existence of large stretches of lightly used native forest, raises the question of what maintained Tuamotu Kingfisher populations before agricultural development. Perhaps the prehistoric primary habitat of the Tuamotu Kingfishers is now entirely absent from the island of Niau and the birds are making the best of a bad situation. Prior to agricultural intensification, Niau lowlands were likely characterized by mixed tropical broadleaf forests with open understory (Mueller-Dombois and Fosberg 1998). Those broadleaf forests, which are now entirely absent from Niau (Butaud 2007), might have sustained a Tuamotu Kingfisher population that was more robust than the contemporary population in agricultural habitats. The utility of native lowland tropical forests to Tuamotu Kingfishers is speculative, however, because no opportunity exists to study the birds in the indigenous habitat.

Alternatively, coconut agriculture may form an ecological trap (Schlaepfer et al. 2002) that lures Tuamotu Kingfishers away from habitats that supply long-term population benefits. Perhaps the birds would successfully use feo forest if coconut agriculture was not present on Niau. However, the limited use of feo forest by birds included in our investigation and the functional structure of the feo forests suggested otherwise. Feo forests are tremendously dense, and the substrate is jagged coral that provides few foraging opportunities from the ground and ample cover for potential prey to hide from hunting birds.

Our results suggest that structural characteristics of agricultural coconut forest benefit Tuamotu Kingfishers, but habitat is only one of the factors with the potential to affect the population. Like most oceanic islands, Niau prehistorically had no mammalian predators. Now there are robust populations of rats and domestic cats that might affect Tuamotu Kingfishers through predation (Gouni et al. 2006). Introduced predators devastated other native populations of birds throughout Oceania. For example, the Brown Tree Snake (*Bioga irregularis*) was responsible for the extirpation or extinction of 12 birds on Guam (Savidge 1987, Wiles et al. 2003), and introduced mammals had similar effects on avifauna throughout the Pacific (Courchamp et al. 2003). Thus, additional research into the utility of prehistoric broadleaf forests and studies of Tuamotu Kingfisher demography might

provide further insight into the reasons for the small population of Tuamotu Kingfishers.

*Management and conservation implications.*—Our results lend support to recent calls for including human-modified landscapes in conservation plans for tropical biodiversity and for forming alliances with local stakeholders when designing conservation management plans (Bhagwat et al. 2008, Chazdon et al. 2009). Collaboration with Niau copra farmers is critical for preserving the Tuamotu Kingfisher within its native range. Retaining a mosaic of exposed ground, plant litter, and ground cover might enhance the abundance and visibility of lizards and other prey items (D. Zarzo-Lacoste unpubl. data). In addition, broadleaf trees within agricultural areas would provide hunting perches and shade for the species. Tuamotu Kingfishers also require perches for nest building, because they initiate excavation by repeatedly going back and forth between the perch and the snag, colliding bill-first into the trunk. Excavation is a pair-bonding activity and requires coordination between the mates. Retention of dead standing coconut trees should be encouraged, because they are now the Tuamotu Kingfisher's sole nesting substrate.

Previous conservation recommendations for Pacific birds, including Tuamotu Kingfishers (Gouni et al. 2006), suggested the establishment of rescue populations in other locations. Some authors supported conservation investments in natural tropical forests over agroforestry (Edwards et al. 2010), and others suggested that large coconut plantations should be restored to native vegetation types prior to avian translocations (Franklin and Steadman 1991). However, coconut is one of the most extensive vegetation types on tropical Pacific islands, and little native lowland forest remains (Mueller-Dombois and Fosberg 1998). Many islands in French Polynesia are characterized by agricultural coconut habitats similar to those on Niau, and our results suggest that these should be considered for assisted colonization. The large island complex of Anaa, for example, has extensive coconut and feo forests and wetlands, similar in composition to those on Niau (D. C. Kesler pers. obs.). In addition to habitat composition, conservation managers should also ensure that potential release sites include abundant hunting perches and exposed ground to create acceptable foraging habitat. Assessing the availability of prey, lizards in particular, would also provide indications of suitability for assisted colonization of Tuamotu Kingfishers. Finally, on both Niau and potential translocation destinations, management of introduced predators is also recommended.

Resource and demographic information has already been broadly applied across Pacific Tuamotu Kingfisher populations for conservation (e.g., Kesler and Haig 2007a, b; U.S. Fish and Wildlife Service 2008), and we believe that our results may also extend to other species. Insular Pacific Tuamotu Kingfishers are threatened throughout Oceania, and the group may benefit from managed coconut habitats and restored native vegetation. Other kingfisher species that were previously observed using coconut agriculture include the Marquesan Kingfisher (*T. godeffroyi*), Mangaia Kingfisher (*T. ruficollaris*), and Sombre Kingfisher (*T. funebris*; BirdLife International 2010b). Additionally, prior to the bird's extirpation from Guam by the Brown Tree Snake (Savidge 1987), the highest densities of the Micronesian Kingfisher (*T. cinnamominus cinnamominus*) were recorded in areas with prominent coconut stands (Engbring and Ramsey 1984) and the birds used coconut trees for nesting (Marshall 1989).



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## LITERATURE CITED

- AEBISCHER, N. J., P. A. ROBERTSON, AND R. E. KENWARD. 1993. Compositional analysis of habitat use from animal radio-tracking data. *Ecology* 74:1313–1325.
- ANDRÉFOUËT, S., C. CHAUVIN, S. SPRAGGINS, D. TORRES-PULLIZA, AND C. KRANENBURG. 2005. Atlas des récifs coralliens de Polynésie française. IRD, Nouméa, Nouvelle-Calédonie.
- ARMSTRONG, D. P., AND P. J. SEDDON. 2008. Directions in reintroduction biology. *Trends in Ecology & Evolution* 23:20–25.
- BHAGWAT, S. A., K. J. WILLIS, H. J. B. BIRKS, AND R. J. WHITTAKER. 2008. Agroforestry: A refuge for tropical biodiversity? *Trends in Ecology & Evolution* 23:261–267.
- BINGHAM, R. L., AND L. A. BRENNAN. 2004. Comparison of type I error rates for statistical analyses of resource selection. *Journal of Wildlife Management* 68:206–212.
- BINGHAM, R. L., L. A. BRENNAN, AND B. M. BALLARD. 2007. Misclassified resource selection: Compositional analysis and unused habitat. *Journal of Wildlife Management* 71:1369–1374.
- BIRDLIFE INTERNATIONAL. 2000. Threatened Birds of the World. Lynx Edicions and BirdLife International, Barcelona, Spain.
- BIRDLIFE INTERNATIONAL. 2003. EBA factsheet: Tuamotu Archipelago. In BirdLife's Online World Bird Database: The Site for Bird Conservation, version 2.0. BirdLife International, Cambridge, United Kingdom. [Online.] Available at [www.birdlife.org/datazone/ebas](http://www.birdlife.org/datazone/ebas).
- BIRDLIFE INTERNATIONAL. 2010a. A range of threats drives declines in bird populations. [Online.] Available at [www.biodiversityinfo.org/casestudy.php?r=&id=102](http://www.biodiversityinfo.org/casestudy.php?r=&id=102).
- BIRDLIFE INTERNATIONAL. 2010b. Species factsheets: *Todiramphus* spp. [Online.] Available at [www.birdlife.org/datazone/species](http://www.birdlife.org/datazone/species).
- BLACKBURN, T. M., P. CASSEY, R. P. DUNCAN, K. L. EVANS, AND K. J. GASTON. 2004. Avian extinction and mammalian introductions on oceanic islands. *Science* 305:1955–1958.
- BLOCK, W. M., AND L. A. BRENNAN. 1993. The habitat concept in ornithology: Theory and applications. Pages 35–91 in *Current Ornithology*, vol. 11 (D. M. Power, Ed.). Plenum Press, New York.
- BUCKLEY, L. B., AND W. JETZ. 2007. Insularity and the determinants of lizard population density. *Ecology Letters* 10:481–489.
- BURNHAM, K. P., AND D. R. ANDERSON. 2002. Model Selection and Multimodel Inference: A Practical Information-Theoretic Approach, 2nd ed. Springer-Verlag, New York.
- BUSKIRK, S. W., AND J. J. MILLSPAUGH. 2006. Metrics for studies of resource selection. *Journal of Wildlife Management* 70:358–366.
- BUTAUD, J. 2007. Étude de la flore vasculaire de l'atoll soulevé de Niau, cartographie de sa végétation, caractérisation de l'habitat du Martin-Chasseur de Niau, et priorités de conservation (Société d'ornithologie de Polynésie «Manu», Ed.). Papeete, French Polynesia.
- CHAZDON, R. L., C. A. HARVEY, O. KOMAR, D. M. GRIFFITH, B. G. FERGUSON, M. MARTINEZ-RAMOS, H. MORALES, R. NIGH, L. SOTO-PINTO, M. VAN BREUGEL, AND S. M. PHILPOTT. 2009. Beyond reserves: A research agenda for conserving biodiversity in human-modified tropical landscapes. *Biotropica* 41:142–153.
- COULOMBE, G. L. 2010. Resource selection and space use of the critically endangered Tuamotu Kingfisher. M.S. thesis, University of Missouri, Columbia.
- COURCHAMP, F., J.-L. CHAUPUIS, AND M. PASCAL. 2003. Mammal invaders on islands: Impact, control and control impact. *Biological Reviews* 78:347–383.
- DIAMOND, J. M. 1984. "Normal" extinctions of isolated populations. Pages 191–246 in *Extinctions* (M. H. Nitecki, Ed.). University of Chicago Press, Chicago, Illinois.
- DUPON, J. F. 1986. Atolls and the cyclone hazard: A case study from the Tuamotu Islands. SPREP Environmental Case Studies, South Pacific Study 3.
- EDWARDS, D. P., J. A. HODGSON, K. C. HAMER, S. L. MITCHELL, A. H. AHMAD, S. J. CORNELL, AND D. S. WILCOVE. 2010. Wildlife-friendly oil palm plantations fail to protect biodiversity effectively. *Conservation Letters* 3:236–242.
- ENGBRING, J., AND F. L. RAMSEY. 1984. Distribution and abundance of the forest birds of Guam: Results of a 1981 survey. U.S. Fish and Wildlife Service, Honolulu, Hawaii.
- FORDHAM, D., AND B. BROOK. 2010. Why tropical island endemics are acutely susceptible to global change. *Biodiversity and Conservation* 19:329–342.
- FRANKLIN, J., AND D. W. STEADMAN. 1991. The potential for conservation of Polynesian birds through habitat mapping and species translocation. *Conservation Biology* 5:506–521.
- GAUNT, A. S., L. W. ORING, K. P. ABLE, D. W. ANDERSON, L. F. BAPTISTA, J. C. BARLOW, AND J. C. WINGFIELD. 1999. Guidelines to the Use of Wild Birds in Research, 2nd ed. Ornithological Council, Washington, D.C.
- GOUNI, A., D. C. KESLER, R. SARSFIELD, T. TEHEI, J. GOUNI, J. BUTAUD, L. BLANC, J. DURIEUX, J. MARIE, AND A. LICHTLÉ. 2006. Étude du Martin-chasseur des Gambier (*Todiramphus gambieri niauensis*) sur l'atoll de Niau (Société d'Ornithologie de Polynésie «Manu», Ed.). Papeete, French Polynesia.
- GOUNI, A., AND T. ZYSMAN. 2007. Oiseaux du Fenua—Tahiti et ses îles. Tethys Editions, Tahiti, French Polynesia.
- HOLYOAK, D. T., AND J. C. THIBAUT. 1984. Contribution à l'étude des oiseaux de Polynésie orientale. Mémoires du Muséum National d'Histoire Naturelle 127:1–209.
- HOSMER, D. W., AND S. LEMESHOW. 2000. Applied Logistic Regression, 2nd ed. Wiley, New York.
- INEICH, I., A. GOUNI, L. BLANC, J. DURIEUX, AND J. BUTAUD. 2007. Lizards of Niau Atoll, Tuamotu Archipelago, French Polynesia. *Herpetological Review* 38:491–492.

- IUCN. 1987. Position statement on translocation of living organisms: Introductions, re-introductions, and re-stocking. Species Survival Commission, Commission on Ecology, and Commission on Environmental Policy, Law, and Administration, Gland, Switzerland.
- IUCN. 1998. Guidelines for re-introductions. IUCN/SSC Re-introduction Specialist Group, Gland, Switzerland, and Cambridge, United Kingdom. [Online.] Available at [www.iucnsscscrg.org/download/English.pdf](http://www.iucnsscscrg.org/download/English.pdf).
- JETZ, W., D. S. WILCOVE, AND A. P. DOBSON. 2007. Projected impacts of climate and land-use change on the global diversity of birds. *PLoS Biology* 5:e157.
- JOHNSON, D. H. 1980. The comparison of usage and availability measurements for evaluating resource preference. *Ecology* 61:65–71.
- JOHNSON, T. H., AND A. J. STATTERSFIELD. 1990. A global review of island endemic birds. *Ibis* 132:167–180.
- JONES, J. 2001. Habitat selection studies in avian ecology: A critical review. *Auk* 118:557–562.
- KESLER, D. C. 2011. Non-permanent radiotelemetry leg harness for small birds. *Journal of Wildlife Management* 75:467–471.
- KESLER, D. C., AND S. M. HAIG. 2007a. Conservation biology for suites of species: Demographic modeling for Pacific island kingfishers. *Biological Conservation* 136:520–530.
- KESLER, D. C., AND S. M. HAIG. 2007b. Multiscale habitat use and selection in cooperatively breeding Micronesian Kingfishers. *Journal of Wildlife Management* 71:765–772.
- KESLER, D. C., AND S. M. HAIG. 2007c. Territoriality, prospecting, and dispersal in cooperatively breeding Micronesian Kingfishers (*Todiramphus cinnamominus reichenbachii*). *Auk* 124:381–395.
- KESLER, D. C., I. F. LOPES, AND S. M. HAIG. 2006. Sex determination of Pohnpei Micronesian Kingfishers using morphological and molecular genetic techniques. *Journal of Field Ornithology* 77:229–232.
- LEBAN, F. 1999. Resource Selection for Windows, version 1.00 beta 8.4. [Online.] Available at [www.cnrhome.uidaho.edu/fishwild/Garton/tools](http://www.cnrhome.uidaho.edu/fishwild/Garton/tools).
- MARIE, J. 2006. Biodiversité, biologie de la conservation et recherches en entomologie médicales: prospection entomologique sur l'atoll de Niau (Institut Louis Malardé, Ed.). Papeete, French Polynesia.
- MARSHALL, S. D., 1989. Nest sites of the Micronesian kingfisher on Guam. *Wilson Bulletin* 101:472–477.
- MARTIN, T. E. 1987. Food as a limit on breeding birds: A life-history perspective. *Annual Reviews in Ecology and Systematics* 18:453–487.
- MARZLUFF, J. M., J. J. MILLSAUGH, P. HURVITZ, AND M. S. HANDCOCK. 2004. Relating resources to a probabilistic measure of space use: Forest fragments and Steller's Jays. *Ecology* 85:1411–1427.
- MILBERG, P., AND T. TYRBERG. 1993. Naive birds and noble savages—A review of man-caused prehistoric extinctions of island birds. *Ecography* 16:229–250.
- MILLSAUGH, J. J., R. M. NIELSON, L. McDONALD, J. M. MARZLUFF, R. A. GITZEN, C. D. RITTENHOUSE, M. W. HUBBARD, AND S. L. SHERIFF. 2006. Analysis of resource selection using utilization distributions. *Journal of Wildlife Management* 70:384–395.
- MUELLER-DOMBOIS, D., AND F. R. FOSBERG. 1998. *Vegetation of the Tropical Pacific Islands*. Springer, New York.
- NEWTON, I. 1994. The role of nest sites in limiting the numbers of hole-nesting birds: A review. *Biological Conservation* 70:265–276.
- NEWTON, I. 1998. *Population Limitation in Birds*. Academic Press, San Diego, California.
- OLSON, S. L., AND H. F. JAMES. 1982. Fossil birds from the Hawaiian Islands: Evidence for wholesale extinction by man before Western contact. *Science* 217:633–635.
- R DEVELOPMENT CORE TEAM. 2009. R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna. [Online.] Available at [www.R-project.org](http://www.R-project.org).
- SAVIDGE, J. A. 1987. Extinction of an island forest avifauna by an introduced snake. *Ecology* 68:660–668.
- SCHLAEPFER, M. A., M. C. RUNGE, AND P. W. SHERMAN. 2002. Ecological and evolutionary traps. *Trends in Ecology & Evolution* 17:474–480.
- SEAMAN, D. E., AND R. A. POWELL. 1996. An evaluation of the accuracy of kernel density estimators for home range analysis. *Ecology* 77:2075–2085.
- SEAMAN, E., B. GRIFFITH, AND R. POWELL. 1998. KernelHR: A program for estimating animal home ranges. *Wildlife Society Bulletin* 26:95–100.
- SEITRE, R., AND J. SEITRE. 1992. Causes of land-bird extinctions in French Polynesia. *Oryx* 26:215–222.
- STEADMAN, D. W. 1997. Human-caused extinction of birds. Pages 139–161 *in* *Biodiversity II: Understanding and Protecting Our Biological Resources* (M. L. Reaka-Kudla, D. E. Wilson, and E. O. Wilson, Eds.). Joseph Henry Press, Washington, D.C.
- STEADMAN, D. W. 2006. *Extinction and Biogeography of Tropical Pacific Birds*. University of Chicago Press, Chicago, Illinois.
- TCHOUKANSKI, I. 2009. ET GeoWizards, version 9.9. ET Spatial Techniques, Pretoria, South Africa. [Online.] Available at [www.ian-ko.com](http://www.ian-ko.com).
- THOMAS, D. L., AND E. J. TAYLOR. 2006. Study designs and tests for comparing resource use and availability II. *Journal of Wildlife Management* 70:324–336.
- TOWNS, D. R., I. A. E. ATKINSON, AND C. H. DAUGHERTY. 2006. Have the harmful effects of introduced rats on islands been exaggerated? *Biological Invasions* 8:863–891.
- U.S. FISH AND WILDLIFE SERVICE. 2008. Revised recovery plan for the Sihek or Guam Micronesian Kingfisher. U.S. Fish and Wildlife Service, Portland, Oregon.
- WAITE, S. 2000. *Statistical Ecology in Practice: A Guide to Analysing Environmental and Ecological Field Data*. Pearson Education Limited, Harlow, England.
- WHITE, G. C., AND R. A. GARROTT. 1990. *Analysis of Wildlife Radio-Tracking Data*. Academic Press, San Diego, California.
- WHITTAKER, R. J., AND J. M. FERNANDEZ-PALACIOS. 2007. *Island Biogeography: Ecology, Evolution, and Conservation*, 2nd ed. Oxford University Press, New York.
- WILES, G. J., J. BART, R. E. BECK, JR., AND C. F. AGUON. 2003. Impacts of the brown tree snake: Patterns of decline and species persistence in Guam's avifauna. *Conservation Biology* 17:1350–1360.
- WILSON, E. O. 2002. *The Future of Life*. Knopf, New York.
- WOLF, C. M., T. GARLAND, AND B. GRIFFITH. 1998. Predictors of avian and mammalian translocation success: Reanalysis with phylogenetically independent contrasts. *Biological Conservation* 86:243–255.