A REVIEW OF SELECTED SURVEYS OF THE KITTLITZ'S MURRELET *BRACHYRAMPHUS BREVIROSTRIS* IN ALASKA: LESSONS LEARNED

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Received 30 April 2010, accepted 22 May 2011

SUMMARY

KIRCHHOFF, M.D. 2011. A review of selected surveys of the Kittlitz's Murrelet *Brachyramphus brevirostris* in Alaska: lessons learned. *Marine Ornithology* 39: 77–83.

I reviewed methods and results of selected nearshore surveys conducted in Alaska over the past 30 years to identify common challenges and to suggest ways for improving the precision and accuracy of monitoring populations of Kittlitz's Murrelet *Brachyramphus brevirostris*. Boat-based surveys for Kittlitz's Murrelet are especially challenging because this relatively rare species is difficult to detect and identify at a distance and has a clumped or contagious distribution. This review suggests a number of changes in the design and conduct of surveys that could yield improved precision and accuracy. These include (1) increasing the proportion of survey effort in offshore waters, (2) orienting transects to sample across the nearshore density gradient, (3) using distance sampling methods to account for variable detection probabilities, (4) sampling over larger geographic areas and at multiple times during the summer, (5) improving species identification rates, and (6) using a "snapshot" count to enumerate flying birds. It is important to repeat the same survey design and protocol in a given survey area over time, but, depending on site-specific attributes such as bird numbers and distribution, physical environment and available resources to conduct surveys, no single approach will be optimal for all areas.

Key words: Kittlitz's Murrelet, *Brachyramphus brevirostris*, Marbled Murrelet, *Brachyramphus marmoratus*, survey methods, transects, population trends, flying birds, Alaska

INTRODUCTION

Kittlitz's Murrelet *Brachyramphus brevirostris* is a species of conservation concern because of its relatively small global population size and suspected declines across its range in Alaska (US Fish and Wildlife Service 2010). The species is found widely, but patchily, along coastal Alaska and northeastern Russia (Day *et al*. 1999, US Fish and Wildlife Service 2010). Breeding occurs in coastal mountains in southeastern and south-central Alaska, the Aleutian Islands, and along both sides of the Bering Sea (US Fish and Wildlife Service 2010). In contrast to most seabirds, the Kittlitz's Murrelet does not breed in colonies, but nests individually and cryptically (Day *et al*. 1999). Surveys for this species must therefore be conducted at sea.

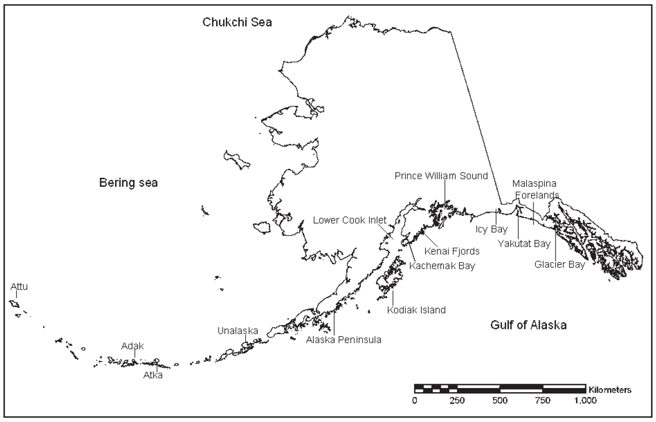

Fig. 1. Locations of at-sea surveys of Marbled and Kittlitz's murrelets in Alaska.

At-sea surveys designed to document the general distribution and abundance of seabirds in inside waters of Alaska were initiated in the mid-1970s in Prince William Sound (Isleib & Kessel 1973) and Kenai Fjords (Bailey 1976) and were subsequently expanded to include other survey areas across the breeding range of Kittlitz's Murrelets (Fig 1). Notwithstanding efforts to standardize surveys for marine birds in Alaska (Gould & Forsell 1989), differences in design and methods remain, not only among areas, but within areas over time, which complicates efforts to detect trends.

Early surveys were designed to describe large-scale distribution and abundance of all seabird and marine mammal species in nearshore waters (Isleib & Kessel 1973, Bailey 1976, Piatt *et al*. 1991). While those surveys were useful for estimating abundance of most species observed, tailoring surveys to the temporal and spatial distribution patterns of *Brachyramphus* murrelets can increase accuracy and precision of abundance estimates (Rachowicz *et al*. 2006, Kissling *et al*. 2007b). In reviewing past surveys, I identified some common challenges that arise in surveying all nearshore species. In this paper, I highlight specific issues related to the Kittlitz's Murrelet, such as misidentification when birds are intermingled with the more common Marbled Murrelet *B. marmoratus*, and how the distribution of murrelets relative to environmental gradients influences surveys. Finally, I suggest ways surveys can be modified to yield more precise and accurate population and trend estimates for the Kittlitz's Murrelet.

PAST SURVEYS

Surveys of nearshore waters in Alaska have been conducted at a wide range of scales, from large regional efforts (Agler *et al*. 1998, Kendall & Agler 1998) to surveys of selected fjords (Kuletz *et al*. 2003, 2008) and islands (Meehan 1996, Piatt *et al*. 2005, Romano & Piatt 2005, Romano *et al*. 2005). These surveys have some elements in common and others that are quite different (Table 1). Surveys were all boat-based (from inflatable boats to crewed vessels) and were typically conducted in mid-summer (June–July) during the breeding season. Both fixed-width strip transects and line transects with distance sampling (Buckland *et al*. 2001) were used, but strip transects were the most common method. Most surveys included a component of sampling effort in the shoreline stratum (typically <300 m from shore) and a component of effort in the offshore stratum (typically >300 m from shore), where sampling occurred on crossing, zigzag or mid-channel transects. Almost all surveys that counted flying birds did so continuously as the birds passed through a defined zone (i.e. forward window) in front of the vessel. In many survey areas, the specific design and methodology changed over time, complicating efforts to estimate trends. Glacier Bay, which supports one of the largest breeding concentrations of Kittlitz's Murrelet, provides an example of the wide range of designs employed over time (Table 2).

ISSUES

Survey objectives

It is useful to state the objectives and assumptions of a survey explicitly. For example, if the objective is to obtain an estimate of the global population, one might choose to distribute sampling

TABLE 1
Survey designs and methods used in areas with estimated Kittlitz's Murrelet population >1000 birds on highest survey in the last 10 years (as reported by USFWS [2010])

Area	High year	Survey date	Transect type	Strip width, m	Offshore transect orientation	Shoreline transect, m from shore	Flying bird count	Forward window W × L, m	Source
Prince William Sound	2007	July	Strip	200	N-S lines in random blocks	100	Continuous	200 × 100	McKnight *et al.* (2008)
Kachemak Bay	2006	July	Strip	200	Crossing	–	Continuous	200 × 100	Kuletz *et al.* (2008)
Glacier Bay	2009	July	Strip	300	Zigzag	–	Continuous	300 × 150	Kirchhoff *et al.* (2010)
Icy Bay	2008	July	Line	–	Crossing	–	Continuous	300 × 300	Kissling *et al.* (2011)
Yakutat Bay	2009	June	Line	–	Zigzag	–	Continuous	300 × 300	Kissling *et al.* (2011)
South Alaska Peninsula	2003	June July	Strip	300	Crossing & shoreline	<500	Continuous	300 × 150	Van Pelt & Piatt (2005)
Unalaska	2005	June	Strip	200, 300	Variable	<500	Continuous	200 × 200 300 × 300	Romano *et al.* (2005)

TABLE 2
Survey designs and methods used to estimate population size or trend of Kittlitz's Murrelet within Glacier Bay, 1987–2010

Years	Timing	Method	Strip width, m	Offshore transect orientation	Shoreline transects, m to shore	Flying bird count	Forward window, W × L, m	Source
1987, 1989, 1991	May–Aug	Strip	200	–	Variable	Continuous	200 × 50	Duncan & Climo (1991)
1991	June–July	Strip	200	Crossing	100	Continuous	200 × 200	Drew & Piatt (2008)
1993	June	Strip	300	Zigzag	–	Continuous	300 × 150	Lindell (2005)
1999–2003	June	Strip	200, 300	Crossing	100, 150	Continuous	200 × 200 300 × 300	Drew *et al.* (2008)
2007	July	Line & strip	200	Perpendicular	–	–	–	Kirchhoff (2008)
2008	June	Line	–	Crossing	100	Continuous	200 × 100	Arimitsu & Piatt (unpublished data)
2009	July	Strip	300	Zigzag	–	Continuous	300 × 150	Kirchhoff *et al.* (2010)
2010	July	Line & strip	300	Zigzag	–	Snapshot & continuous	300 × 150	Kirchhoff & Lindell (2011)
2009–10	July	Line	–	Perpendicular & Zigzag	–	Continuous	400 × 200	Hoekman *et al.* (2011a,b)

effort randomly or systematically across a species' range. If the objective is to detect population trends, it may be adequate to survey in a selected number of the species' population centers, or index areas, as a reflection of trends in the overall population (Johnson 2008). In this paper, I considered estimating population trend to be the primary objective, and obtaining estimates of population size within each index area to be a secondary objective. Measuring population size is more challenging than assessing population trend from index counts, but the objectives are compatible.

Spatial distribution

To obtain a precise and accurate density estimate for a specific population center, prior knowledge of the boundaries of that area, and how the birds are distributed within it, can be very useful for designing the survey. The spatial extent of the population is clear when surveying a discrete embayment such as Glacier Bay (Drew *et al*. 2008) or Prince William Sound (Agler *et al*. 1998). However, when the population is located beside an island (e.g. Romano *et al*. 2005) or along a length of mainland shoreline (e.g. van Pelt & Piatt 2003, 2005, Kissling *et al*. 2007a), the defining boundary (distance offshore, linear extent) is somewhat arbitrary. Measuring density of birds close to a section of shore in such settings may be useful for assessing trends, but extrapolating to a meaningful total population size can be problematic.

Within the breeding range, the densest population centers of Kittlitz's Murrelets are found in glacially active regions, often in association with tidewater glaciers (Day *et al*. 1999, Day *et al*. 2000, Kuletz *et al*. 2003), but some are found in areas without tidewater glaciers (Kissling *et al*. 2007a, Stenhouse *et al*. 2008, Kaler *et al*. 2009). Even in areas with tidewater glaciers, the birds may be far (>10 km) from any significant glacial influence in some years (Kuletz *et al*. 2003, Romano *et al*. 2007, Kirchhoff & Lindell 2011). This distribution pattern suggests some survey effort should be devoted to all waters within a surveyed region, both glacial and non-glacial, so that shifts between these two strata are detected.

Although sampling should be carried out in all available habitats, increasing survey effort in areas of predictable concentration can increase precision and accuracy (Rachowicz *et al*. 2006, Kissling *et al*. 2007b, Raphael *et al*. 2007). Allocating survey effort between shoreline and offshore strata to reflect the distribution of a particular species can improve power to detect trends (Drew *et al*. 2008). For Kittlitz's Murrelets this distribution pattern varies across study areas. In Glacier Bay, the mean density of Kittlitz's Murrelet in the offshore stratum was three times greater than in the shoreline stratum (Drew *et al*. 2008). In Kenai Fjords, the density of Kittlitz's Murrelet in the offshore stratum was 62 times greater than in the shoreline stratum (Romano *et al*. 2006). In Kachemak Bay, the density of Kittlitz's Murrelets in the offshore stratum was two to four times greater than in the shoreline stratum (Kuletz *et al*. 2008). On the southern coast of the Alaska Peninsula, Kittlitz's Murrelet was most abundant in fjords and bays >500 m from shore (van Pelt & Piatt 2005). However, in Prince William Sound, most feeding by Kittlitz's Murrelets was observed in the shoreline stratum rather than further offshore (Day & Nigro 2000).

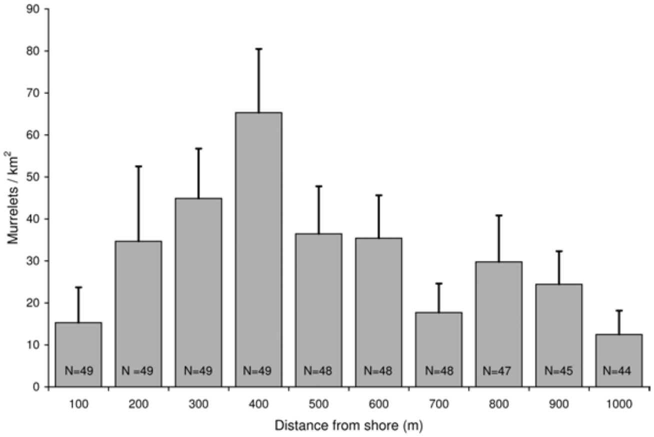

Fig. 2. Mean density (birds/km^2 and SE) of *Brachyramphus* murrelets at varying distances (m) from the shoreline in Glacier Bay, Alaska (from Kirchhoff 2008). N = number of 100 m segments surveyed. Labels on x-axis represent the outer extent of each 100 m bin.

Despite low densities of Kittlitz's Murrelet within 300 m of shore in most areas, a higher level of effort in early surveys was allocated to the shoreline. Sampling intensity in the shoreline stratum was 13 times greater than in the offshore stratum in Prince William Sound (Agler *et al*. 1998), 18 times greater in Lower Cook Inlet (Agler *et al*. 1998), and five to six times greater in Glacier Bay (Drew *et al*. 2008). In some surveys, all, or nearly all, of the survey effort was allocated to the shoreline stratum (Bailey 1976, Piatt *et al*. 1991). Emphasizing a stratum with few birds is less than optimal if the goal is high power to detect trends. In Glacier Bay, for example, the maximum power to detect trends in Kittlitz's Murrelet population was achieved when approximately 4% of the survey effort was placed in the shoreline stratum (Drew *et al*. 2008).

Although *Brachyramphus* murrelet densities along the shore are often quite low, distribution of Marbled Murrelets has been shown to peak between the shoreline and 1–2 km from shore (Burger 1995, Ralph & Miller 1995, Strachan *et al*. 1995, Burger *et al*. 2008, Wong *et al*. 2008). There are fewer comparable data for Kittlitz's Murrelet, but, in Glacier Bay, this species occurs farther offshore than the Marbled Murrelet (Robards *et al*. 2003). And there is evidence of a peak in murrelet density just beyond the boundary of the typical shoreline stratum (Fig. 2). Given the steepness of this gradient, even slight departures in transect distance from shore may alter the returned density several-fold. When the density of murrelets is sensitive to distance from shore, orienting transects across this gradient (perpendicular, or angular, to shore) is preferable to a single transect parallel to shore (Rachowicz *et al*. 2006, Kissling *et al*. 2007b, Kirchhoff 2008).

Temporal variation

The number of Kittlitz's Murrelets occupying a survey area varies during the breeding season. Adult birds gradually come inshore in spring, where some fraction will initiate nesting (Day *et al*. 1999). Incubation duties will take half of the breeders from the water during active nesting. As nests fail or eggs hatch, incubating birds return to the water, and by late summer birds are departing the breeding areas (Day *et al*. 1999). Abundance estimates can differ depending on when in the breeding cycle surveys are conducted, because a varying proportion of the adult population is on nests and unavailable for detection on the water. That percentage can be explicitly assumed and the total population size adjusted accordingly. For example, at-sea counts during the nesting season in Russia were doubled to adjust for birds on nests (US Fish and Wildlife Service 2010). Because it is unlikely every adult was breeding, this was almost certainly an overestimate (and is no longer common practice); however, it underscores the potential magnitude of such processes on density estimates. Alternatively, surveys might be conducted later in summer, when adult birds are off nests and available for counting on the water.

The power of any survey design to detect population trends requires knowing both within- and among-year components of variance (Hatch 2003). Conducting only one survey does not capture within-year variance, and that variance can be significant (Romano *et al*. 2007). Among-survey variance can be especially high when surveys are conducted at smaller special scales, such as a bay or portion of a fjord. At such scales, the murrelets counted probably do not constitute a "population," but rather a foraging aggregation that may vary widely from survey to survey. Attraction to foraging areas at this scale is often correlated with environmental attributes that vary temporally, such as tidal stage and flow (Kissling *et al*. 2007b) or availability of forage fish (Arimitsu *et al*. 2010). Such counts can be a useful index for monitoring, but the higher variance associated with such surveys means longer periods will likely be needed to detect statistically significant population trends.

A critical influence on power to detect trends in populations is temporal variability in local counts (Gibbs *et al*. 1998). Surveys conducted during the incubation period have lower power to detect trends if there is high interannual variation in the percentage of Kittlitz's Murrelets nesting, as has been documented in the Marbled Murrelet (Peery *et al.* 2004). This source of variation can be avoided by surveying outside the incubation period (e.g. mid-July), when adult birds are on the water and populations are near their peak. Timing of arrival of Kittlitz's Murrelets may change greatly from year to year as well (Robards *et al*. 2003), adding to temporal variability. To reduce the influence of spatial and temporal variability on power to detect trends, conducting more than one survey per year is recommended (Becker *et al*. 1997, Kissling *et al*., 2007b).

Variation in murrelet counts among years is often also high. For example, in Prince William Sound, the reported annual rate of change in Kittlitz's Murrelet populations between surveys has ranged from a decline of 77% per annum to an increase of 245% per annum (Table 3). Although declines of any magnitude are possible, increases of this magnitude show that factors besides annual recruitment are involved. Some of the difference may reflect measurement errors in one survey or the other (e.g. variable bird identification skills, variable visibility or sea state). It may also reflect an anomalous flux of nonresident birds into a survey area in a single year or a large variation in nesting effort in one year that removes or adds many birds from the water (Peery *et al*. 2004). Finally, it may simply reflect high sampling variance, which is expected in any survey of relatively rare, clumped organisms. Increasing survey effort (area surveyed and number of surveys) is one way to overcome this last obstacle.

Incomplete detection

A central assumption of strip transects is that 100% of the objects (in this case, murrelets) within the strip are detected (Buckland *et al*. 2001). That assumption is rarely satisfied, and, if counts are not adjusted for undetected birds, results will be biased (Thompson 2002). Different researchers have implemented surveys for *Brachyramphus* murrelets using different widths of strip transects. For example, Drew *et al*. (2008) estimated that small birds could be reasonably detected 200–300 m from the observer, while Raphael *et al*. (2007) thought murrelets could be detected up to 200 m perpendicularly from the transect line. Most strip surveys have adopted transect half-widths of 100 m or 150 m (Tables 1, 2). From distance sampling, the approximate detection probabilities range from 40–65% depending on conditions (Kirchhoff 2008, Ronconi & Burger 2009).

Factors that affect detection rates include weather and sea conditions, observer skill and vessel size (observer height), among other factors, all of which may vary from survey to survey. This introduces confounding variance and erodes power to detect trends. Line transects, which correct for incomplete detection, return more accurate and precise population estimates than strip transects (Raphael *et al*. 2007, Ronconi & Burger 2009) and should almost always be preferred. Useful guidance on model selection and other aspects of analyzing murrelet data collected using distance sampling methods is provided by Raphael *et al*. (2007) and Ronconi & Burger (2009).

Murrelet identification

Marbled Murrelets and Kittlitz's Murrelets co-occur over much of the Kittlitz's Murrelet range. The two species are similar in size, shape, color and behavior, and can be difficult to distinguish from one another, especially at a distance or in poor light conditions. For species that occur in roughly equal numbers, misidentification is not a problem as long as both species are equally misidentified. But when the species ratio is heavily skewed, as is typical in most murrelet study areas, misidentification has a large effect on the rarer species. In Prince William Sound, for example, the percentage of *Brachyramphus* murrelets identified as Kittlitz's Murrelet has ranged from 0.5 to 7.0% (Table 3). If a population is composed of 2% Kittlitz's Murrelets, a survey that misclassifies 1% of each species results in a large increase in the Kittlitz's Murrelet

TABLE 3
Among-year variation in Kittlitz's Murrelet population estimates and percentage of *Brachyramphus* murrelets identified as Kittlitz's Murrelets in Prince William Sound, 1989–2007 (McKnight *et al.* 2008)[a]

Year	Kittlitz's Murrelet population	Change since previous survey, %	Per annum change, %	% Kittlitz's Murrelet in murrelet population
1989	6436	–	–	6.0
1990	5231	-19	-19	6.5
1991	1184	-77	-77	1.1
1993	2710	129	64	1.7
1996	1280	-53	-18	1.6
1998	279	-78	-39	0.5
2000	1033	270	135	1.9
2004	780	-24	-6	2.1
2005	2689	245	245	6.2
2007	2346	-13	-6	7.0

[a] The authors included unidentified murrelets with Marbled Murrelets in this report.

population estimate (48%), and a negligible decrease in the Marbled Murrelet population estimate (1%). Because early surveys focused on recording *Brachyramphus* murrelets to genus only (and not on recording Kittlitz's Murrelets specifically), those surveys were more prone to misidentification error.

Given the sensitivity of population estimates to misidentification errors, as much effort as possible should be devoted to accurate species identification in future surveys. Excellent training tools for crews have been developed (Kuletz *et al*. 2008), and some survey protocols allow vessels to slow down as needed to promote accurate species identification (Romano *et al*. 2004, Kirchhoff 2008, Kuletz *et al*. 2008). These protocols should be encouraged. Depending on water conditions and survey platform, positive identification rates in the range of 75–90% should be an attainable goal, and should provide a suitable basis for allocating the unidentified fraction to species.

Flying birds

In most of the at-sea surveys reviewed, flying birds were counted continuously as they passed through a survey window forward of the vessel. The forward window was typically as wide as the strip (e.g. 200–300 m), but varied in length from a transect half-width to a transect full-width (100–300 m) (Tables 1, 2). Because murrelets fly at a high speed (23 m/s, Elliott *et al*. 2004), they pass through this forward window at a higher rate than if they were stationary objects on the water, resulting in an overestimate of flying bird density. This bias can be reduced by taking a "snapshot" count of birds in the forward window (Tasker *et al*. 1984). A snapshot effectively freezes the birds in space, and allows an unbiased count of flying birds. However, as Gaston *et al*. (1987) point out, no count is truly instantaneous, and some degree of positive bias will remain.

Gould & Forsell (1989) recommended using the snapshot count method for surveys in Alaska but recognized that knowing where one forward window ends and the next begins is difficult because of the lack of reference points on the water. They suggested snapshot counts be done at regular time intervals as an approximation. In Glacier Bay, crews counted flying birds continuously, while also conducting snapshot counts at 35 s intervals (Kirchhoff & Lindell 2011). The mean density of flying murrelets measured on snapshot counts (1.4 birds/km^2; n = 1682 snapshots) was 14.7% of the murrelet density measured on continuous counts (9.6 birds/km^2).

Because a small percentage of the population is in the air at any time, trends can also be assessed from birds on the water only, assuming that the proportion of flying birds does not change greatly among years. However, if the objective involves an accurate population estimate, snapshot counts will improve accuracy.

RECOMMENDATIONS

Based on this review, I offer a number of recommendations for changing existing survey designs and protocols to improve surveys for Kittlitz's Murrelet. These are offered as general principles that can be considered in the development of any monitoring plan and tailored for any given area and set of objectives. (1) Early surveys did not optimally sample shoreline and offshore strata with respect to Kittlitz's Murrelet distribution. Placing more effort in offshore waters (e.g. >200 m from shore) should result in higher encounter rates and increased precision. (2) Murrelets exhibit a density gradient relative to shore that may shift from year to year. Survey lines should be oriented perpendicular to shore, or at angles to shore, so that the entire gradient is sampled. Straight transect lines with established beginning and end points are preferable. (3) Within- and among-year variation in Kittlitz's Murrelet surveys is high. Possible causes include variable breeding effort, movement among sites, variable detection rates associated with weather and a naturally patchy distribution. Increasing survey effort over a larger area, and longer time periods, will stabilize annual point estimates and increase power to detect trends. (4) Strip transects can miss some percentage of murrelets, especially when visibility is low (e.g. because of waves, poor light conditions, etc.). If accurate population or trend estimates are an important objective, adjust counts for undetected birds by making use of line transect and distance sampling methods. (5) Kittlitz's Murrelet survey results are sensitive to small errors in species identification. Observers should aim for identification rates of 80% or higher, with a focus on accurate identification. Unidentified birds can be allocated to species based on the species ratio in identified birds. (6) Continuous counts of flying birds significantly overestimate the density of flying birds. For trend analyses, this is not critical if the bias is similar among years. If an accurate population estimate is the objective, bias can be reduced by using a snapshot method to enumerate birds.

ACKNOWLEDGEMENTS

I thank J. Piatt and J. Hodges for a number of discussions that have informed my thinking about murrelet survey methods and designs. S. Hatch, M. Kissling, M. Raphael, M. Smith, N. Warnock and an anonymous referee provided helpful comments on early drafts of this manuscript.

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