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Abundance and Trends

REVIEW OF TECHNIQUES FOR MEASURING POPULATION TRENDS AT NESTING BEACHES

Techniques for collecting data on sea-turtle nesting beaches have varied in sampling approach, what is counted, and how counts are made. Authors generally do not provide detailed justifications for their data-collection techniques, but they often describe their techniques as appropriate for the existing conditions, particularly on the basis of limitations of nesting-beach access, personnel, and equipment. Historical data-collection techniques often influence current techniques. Given the variation in the range of the population covered and in whether there are data on individual turtles, it is evident that data-collection techniques are also influenced by authors' choices regarding breadth-versus-depth tradeoffs.

Types of Sampling

One-time sampling describes counts made during a short visit to a nesting rookery. Such sampling is used to determine presence and absence and approximate abundance. Data of those kinds are seldom published except when they are the only estimates early in a time series (Addison, 1997; Seminoff, 2002). One-time sampling includes serendipitous sampling based on recorded images, as in the Kemp's ridley (*Lepidochelys kempii*) nesting-female counts from the 1947 Herrera film (Carr, 1963; Hildebrand, 1963).

Reactionary sampling describes counts initiated at the onset of nesting activity. It relies on a reduced initial effort to detect when formal and more extensive efforts would result in counts being made. The most common example of reactionary sampling is counting after the recognition of an arribada (a mass nesting behavior) of ridleys (*Lepidochelys* spp.) (Valverde and Gates, 1999; Solis et al., 2008).

Systematic or periodic sampling is generally used where counts over an extensive population range or among multiple discontinuous beaches is favored over complete temporal coverage. It is used commonly for aerial nesting surveys (Hopkins-Murphy et al., 2001; Benson et al., 2007; Lauret-Stepler et al., 2007) and occasionally for ground surveys (Bjorndal et al., 1999; Sims et al., 2008). Periodicity of sampling may follow variations on a weekly schedule or may be based on tidal cycles that erase previous days' tracks (Hopkins-Murphy et al., 2001).

Sampling by index location and season allows representative locations and season dates to remain constant throughout a time series (McLachlan et al., 2006; Beggs et al., 2007; Marcovaldi and Chaloupka, 2007; Witherington et al., 2009). Although many factors contribute to the selection of index beaches and seasons, indexes are often described by authors as being representative of a population. Choices of index locations are inherently biased by logistical concerns and monitoring history. However, diversity in beach habitat (e.g., wave energy, human development), latitude, and nesting density may buffer those biases and allow representative spatial and temporal trends to be assessed (Witherington et al., 2009). Similarly, broad and consistent seasonal sampling can buffer temporal sampling biases (Witherington et al., 2009; but note the possibility of temporal shifts discussed by Weishampel et al., 2004). Sampling by index locations with variable seasons leads to uncontrolled limits on effort that affects the seasonal coverage of counts (Balazs and Chaloupka, 2004a, 2006).

A census is a count made throughout the nesting range of a population and throughout each nesting season in a time series (Witherington et al., 2009). A census also may include identification of all nesting females in a population; but in practice, researchers have accomplished censuses only for discrete island populations (Chaloupka et al., 2008c). Complete census efforts are expensive and may be unnecessary for obtaining useful measures of abundance to use in assessing trends (Jackson et al., 2008; Sims et al., 2008).

Counts

Assessment of population abundance on nesting beaches may be based on counts of eggs, tracks, nests, and nesting females. Harvested eggs have been counted as representative of reproductive effort and of nesting females on the assumption that there has been a nearly complete harvest. Such counts are seldom published except where they are the only abundance estimates early in a time series (Chan and Liew, 1996). Crawls (tracks) have been counted as representing reproductive effort and nesting females with assumptions of constant nesting success (nests and crawls) and constant clutch frequency (the number of clutches deposited by an individual turtle in a nesting season; Godley et al., 2001). Nests (clutches) have been counted as representing reproductive effort and annual nesting females with assumptions of constant clutch frequency (Beggs et al., 2007; Marcovaldi and Chaloupka, 2007; Witherington et al., 2009). Nesting females have been identified and counted as they attempted to nest (Chaloupka and Limpus, 2001; Balazs and Chaloupka, 2004a, 2006; Dutton et al., 2005; Richardson et al., 2006).

Counting Methods

Interviews to glean historical knowledge have been conducted and historical accounts reviewed to produce count data from informal assessments of nesting abundance (Marcovaldi and Marcovaldi, 1999; Meylan, 1999; Limpus et al., 2003). Those count data are seldom published except where they are the only estimates early in a time series.

Morning-after aerial surveys have recorded tracks and nests by using observers in aircraft flying on the morning after nocturnal nesting attempts (Hopkins-Murphy et al., 2001; Benson et al., 2007; Lauret-Stepler et al., 2007). That method has been used when there has been an extensive population range, discontinuous beaches, and few personnel. The aerial counts are typically calibrated to ground counts. Aerial surveys are often scheduled to correlate with tides that erase the previous day's tracks (Hopkins-Murphy et al., 2001).

Morning-after ground surveys have recorded tracks and nests by using observers on the beach on the following morning (Bjorndal et al., 1999; Marcovaldi and Chaloupka, 2007; Witherington et al., 2009). Old tracks are marked by observers on the previous day, and crawl tracks are appraised to determine species and nesting success (nests and abandoned attempts) (Schroeder and Murphy, 1999; Florida Fish and Wildlife Commission, 2007).

Counting nesting females during arribadas and other high-density nesting is one method of obtaining density estimates. In this method, sampling of turtle density on the beach is used to extrapolate the total number of nesting females (Gates et al., 1996; Valverde and Gates, 1999; Limpus et al., 2003; Solis et al., 2008). A related "stepping index" was used as a unique method for assigning turtle densities on the basis of historical accounts that described people stepping on turtles for measured distances (Limpus et al., 2003).

Tag–recapture estimates based on nesting-female encounters have been made by marking nesting females—typically with flipper tags and internal passive integrated transponder (PIT) tags—during their nesting attempts and reidentifying them as they make later nests (Chaloupka and Limpus, 2001; Balazs and Chaloupka, 2004a, 2006; Dutton et al., 2005). That method has been used to provide counts of turtles within a nesting season and to estimate total nesting females in multiple years. Temporary marks (made with paint) have been used on high-density nesting beaches where later "recapture" observations were made in waters off the nesting beach (Limpus et al., 2005). Tagging efforts on most nesting beaches involve extensive effort, typically at night; these efforts are expensive and may result in adverse effects on nesting turtles (Broderick and Godley, 1999) or other beach species, such as shorebirds (Epstein, 1999).

Modeling Counts and Abundance Estimates

Counts must be assumed to be representative if they are to apply to population abundance. Representativeness is not an issue for censuses, but most counts described as censuses take place on only a portion of a nesting population's range. Composite counts from neighboring projects based on the use of similar techniques within a population range are rare (Witherington et al., 2009), even for individual islands (Chaloupka et al., 2008c). However, reviews of nest and nesting-female counts across multiple projects have attempted to estimate population abundance on the basis of a variety of counting methods (Broderick et al., 2002).

How counts reflect abundance varies with detectability and availability of things counted and with systematic error, such as misidentification due to lost tags. At discrete sampling locations and times, estimates of nesting-female abundance are often modeled by using an observation probability function, such as a Horvitz-Thompson estimator, a general estimator for a population total, which can be used for any probability sampling plan with or without replacement (Balazs and Chaloupka, 2006), or other estimators of population totals used for varied sampling plans and encounter probabilities. The models include covariates (two or more random variables that exhibit correlated variation) that describe how available a nesting turtle is for being counted, given a specified measure of effort. In counting, effort is likely to vary within a time series because of occasional difficulties with weather, personnel, and equipment. When counts are collected as an index (standardized locations and season) and a fine spatiotemporal scale is used, missing data are filled in by using Poisson and negative binomial models (Witherington et al., 2009). Tag-loss models describe the probability of misidentifying previously counted turtles as new ones (Rivalan et al., 2005a). Although that identification error can be factored into models by using reobservation rates of nesting females, technological advances in tag persistence (e.g., PIT tags) have allowed the reduction of this error to insignificant rates.

Because counts made on nesting beaches depend on nesting activity, information on reproductive rates is required if these data are to be used for estimating the abundance of mature females. Reproductive rates often come from more completely monitored nesting beaches, but clutch frequency has recently been determined on the basis of interpretation of satellite transmitter locations (Tucker, 2010). Track counts have the greatest data requirements for estimating mature-female abundance, and counts of nesting females have the fewest data requirements. In each type of annual count, abundance estimates must account for nesting females that skip breeding seasons, which is a common trait in sea turtles. Horwitz–Thompson estimators can allow for the effect of skipped breeding on detection (Dutton et al., 2005) and have provided abundance estimates based on nesting-female counts over multiple nesting seasons. Modeling abundance on the basis of the identification of nesting females requires minimal additional data on reproductive rates because these rates can be measured as part of the method. Identification of nesting females over multiple nesting seasons can also contribute to modeling of mark–recapture rates. Open robust-design modeling using mark–recapture data has provided highly reliable nesting-female abundance estimates and detection probabilities and estimated rates of recruitment, survival, and breeding (Kendall and Bjorkland, 2001; Dutton et al., 2005; Rivalan et al., 2005b; Troëng and Chaloupka, 2007).

REVIEW OF TECHNIQUES FOR MEASURING POPULATION TRENDS IN OCEANIC AND NERITIC HABITATS

Data-collection techniques to measure abundance and other demographic characters of sea turtles in the water vary widely in many of the ways that nesting-beach techniques do. Like authors who report counts and other demographic data collected on nesting beaches, those who report similar data on sea turtles in the water seldom provide detailed justifications but often describe the techniques as appropriate for the conditions. The conditions vary with behavior that is specific to a species or life stage, water depth and clarity, currents and sea state, accessibility of habitat, availability of personnel and equipment, and funding. Some of the efforts continue with standardized methods that have been used historically to assemble comparable datasets.

Incentives to collect demographic information on sea turtles in the water influence the location, timing, and nature of data collection. Few individual research projects are designed to collect population-wide demographic information, and most are focused on local groups of turtles. Other research projects collect demographic information on turtles observed or captured incidentally because of other activities, such as fisheries and power-plant operations. Thus, the location, timing, and nature of research projects are determined by the operations that provide access to sea turtles. Personal preferences of individual researchers also have the potential to influence data-collection techniques. Their preferences may be based on opportunity, skill set, and choices regarding tradeoff between collection of fewer data on more turtles and more data on fewer turtles. In-water project variations notwithstanding, U.S. waters currently have a broadly distributed array of research targeting sea-turtle species (Eaton et al., 2008; Turtle Expert Working Group, 2009). Proceedings of a workshop on in-water sea-turtle population assessments (Bjorndal and Bolten, 2000) provide a useful introduction to application of catch per unit effort (CPUE), transect, and capture–mark–recapture (CMR) methods in these studies.

Types of Sampling

One-time sampling has been used to detect the presence and absence and to approximate the population density of sea turtles in an area, usually when there is a potential for harm from human activities, such as channel dredging or explosions (National Marine Fisheries Service, 1991; Clarke and Norman, 2005). Such counts generally apply to a time- and location-specific relative abundance or density of sea turtles although spatial or seasonal trends might be used to extrapolate results to a broader scale.

Reactionary sampling has occurred at the onset of turtle-access opportunities, such as after cold-stunning events (Witherington and Ehrhart, 1989) or other stranding episodes (Limpus and Reed, 1985a; Hart et al., 2006; Chaloupka et al., 2008b). An important characteristic of reactionary sampling is that effort is variable or not recorded regularly.

Reporting of sea-turtle observations has occurred as an element of long-term programs (as in stranding recovery) or shorter-term projects. In short-term efforts, researchers have asked boat captains, divers, or recreational fishermen to submit sea-turtle observation data (Epperly et al., 1995a; Saladin, 2007). In the social sciences, data from questionnaires and voluntary reports are subjected to extensive statistical assessments for reliability, which accompany common, but controversial, use in quantitative analyses (Manski, 1993). However, use of the reported data in sea-turtle population assessments has been largely qualitative. Reports from biologists who conduct counts of other species, typically with measured effort (James et al., 2006), could be considered as a separate category. However, counting methods and spatiotemporal distribution (over space and time) of effort are likely to be dictated by the need to detect the target species. All data that rely on reporting by second parties might be subject to underreporting (Groves et al., 1992).

Targeted opportunistic effort characterizes many sea-turtle research projects in which effort is measured and sampling locations are predetermined but sampling times are dictated by weather or other haphazard scheduling. Examples include observations or use of equipment, such as nets, that require optimal sea state or other weather conditions. Those targeted sampling efforts may occur within a framework of attempted periodic or seasonal sampling (e.g., Limpus and Reed, 1985b). They may be targeted to a broad area with haphazardly directed searches for turtles in the area. That method was chosen for small-vessel searches within an aquatic refuge with a GPS-recorded search effort (Bresette et al., 2010).

Random sampling of sea-turtle abundance is most commonly used within a stratified schedule (stratified random sampling) in which geographic groups (e.g., grid cells) are sampled independently. Stratified random sampling has been used in trawling capture of sea turtles in shelf waters (Maier et al., 2004). In those efforts, the sampling protocol of the Southeast Area Monitoring and Assessment Program (National Marine Fisheries Service Southeast Fisheries Science Center, 2001) has been used repeatedly for structuring randomized trawl samples in time and space within the southeastern United States; stations are distributed among areas where trawling is possible, and multiple species in addition to sea turtles are targeted. Fishery-observer sampling for sea-turtle bycatch has had sampling effort stratified by the timing and location of fishing effort with fishing vessels selected randomly within each stratum; the strata do not target the highest likelihood of sea-turtle bycatch (Murray, 2008, 2009) and depend on sampling locations and times chosen by vessel operators.

Many sampling efforts to count sea turtles take place at standardized index locations with periodic or haphazard scheduling. Extensive examples of those sea-turtle counting and capture efforts in the southeastern United States are discussed in Eaton et al. (2008) and Turtle Expert Working Group (2009). Authors describing sampling sites as index sites report consistently sampled representative locations chosen for high capture or observation success. Repeated sampling at the locations is often seasonal but varies between and within projects. Index locations are inherently biased by logistical concerns and monitoring history, and temporal sampling is most commonly reported to vary because of unscheduled events. In one example of continuous sampling at an index location, sea turtles are drawn into the intake water of a constantly operating power plant (Bresette et al., 1998). Although index surveys of stranded sea turtles have been proposed (Shaver and Teas, 1999), this method is not used widely for stranding counts in the United States.

Counts

Removed (killed or taken) turtles are commonly counted and are often represented in reports describing the magnitude of threats and mortality factors or in accounts of historical harvest (Witzel, 1994). Removed sea turtles include ones that are bought, sold, or transported. Parts of taken turtles are also reported, such as shell, leather, and meat.

Stranded turtles are counted as turtles that have reached land because of illness, injury, or death and that have been reported by trained observers. The U.S. Sea Turtle Stranding and Salvage Network coordinates reporting of data on those turtles in the southeastern United States and on U.S. islands in the Caribbean Sea (Southeast Fisheries Science Center, 2010). The data are used most commonly in qualitative assessments of abundance (e.g., to detect periodicity in mortality events; Crowder et al., 1995) and generally are presented as a combined function of relative abundance and relative mortality (or morbidity). The data also have been used in conjunction with counts of nesting turtles in the same region to estimate mortality (Epperly et al., 1996). In addition to superimposed effects of abundance and mortality, stranding counts are influenced by physical oceanographic factors, including winds, currents, and temperature (Epperly et al., 1996; Hart et al., 2006). Trends in stranding counts vary with observation and reporting effort (Tomás et al., 2008). Collection of data on stranded sea turtles is discussed in more detail in Chapter 5.

Captured sea turtles are counted either as turtles obtained through targeted efforts or as turtles captured incidentally. Capture of turtles allows researchers to collect data in addition to simple counts and to mark released turtles with tags that identify and track. The additional data allow counts to be divided by categories, such as size, sex, and genetic origin. Tagging, release, and recapture of identified turtles facilitate estimation of abundance and survivorship and allow studies of behavior and physiology (Bjorndal et al., 2003c, 2005).

Observed turtles have been counted from underwater (Leon and Diez, 1999) and from vessels, land, or air and include turtles recorded both at and below the water's surface with varied associated information. These observations have a higher encounter rate per unit effort but have lower information return per encounter than turtle captures. Occasionally, observation counts are made in conjunction with sea-turtle capture efforts (Bresette et al., 2010).

Counting Methods

Sea-turtle abundance has been estimated from interviews (Epperly et al., 1995b; Meylan 1999), historical accounts (Witzel, 1994; Jackson et al., 2001), and archeological data (McClenachan et al., 2006; Allen, 2007). The data are often the only representations of abundance early in a time series. Because of uncertainty in how reports and extrapolations are related to actual abundance, little analysis of these data has been conducted. Some counts are discussed in terms of orders of magnitude of abundance, and harvest data are most commonly presented without measures of associated effort.

Aerial surveys (Kenney and Shoop, in press), vessel surveys (Bresette et al., 2010), and diver surveys (Makowski et al., 2005) of sea turtles are conducted along transects and vary in two important ways: in their geographic scope and in the associated data that allow extrapolation of observations to estimations of turtle density and abundance. Aerial surveys have the largest geographic scope, but there are presumed tradeoffs in low detectability and misidentification of species, especially when flight speeds and altitudes favor marine-mammal target species rather than sea turtles (Marsh and Sinclair, 1989). Most surveys use a variation of line- or strip-transect methods to estimate relative density and abundance from observations. Some surveys are conducted in conjunction with measurements of turtles' surface time so that an availability function can be used to estimate absolute density and abundance (Mansfield, 2006).

Aerial and vessel surveys of sea turtles can vary in objectives, methods, and operating models, and their spatial extent can range from tens to thousands of square kilometers. Since the first ones with light aircraft, most large-scale surveys have applied line-transect theory used for population assessment of marine mammals (Buckland et al., 1993, 2004). The Cetacean and Turtle Assessment Program works to detect seasonal (quarterly) patterns and habitat use and covers about 280,000 km^2 of the northeastern U.S. continental shelf (Shoop and Kenney, 1992). Similarly, in the Gulf of Mexico region, a series of separate geographic blocks were surveyed to portray seasonal distribution and abundance patterns (Fritts et al., 1983). In the southeastern United States, large-scale aerial surveys were used to detect sea turtles from North Carolina to the Florida Keys (e.g., Schroeder and Thompson, 1987); others were conducted in juvenile or estuarine habitats, such as the Carolinas (Braun and Epperly, 1995) and Chesapeake Bay (Musick et al., 1994). Although sea turtles are included and counted in the long-running Southeast Right Whale Survey coordinated by several states, the National Marine Fisheries Service (NMFS), and the New England Aquarium (Slay et al., 2002), the sea-turtle sightings data were not used for assessment purposes. In a detailed review, Kenney and Shoop (in press) present aerial-survey design, sampling limitations, and objectives of specific surveys conducted in the United States and abroad.

The challenges in detecting sea turtles are similar to those in detecting small marine mammals, including glare, sea state, field of view, observer fatigue, and similarity of appearance. Species identification of sea turtles is difficult, even for well-trained, highly experienced observers (e.g., Marsh and Saalfeld, 1989; Henwood and Epperly, 1999). Turtles smaller than 60 cm in carapace length are difficult to detect from fixed-wing aircraft flying at any altitude or speed although smaller ones (25–30 cm) may be identified correctly from airships (lighter-than-air craft; Kenney and Shoop, in press). Research design for aerial assessment of sea turtles is complex, and the surveys are expensive. Estimation of density or absolute abundance presents a number of sensitivity issues (Burnham et al., 1985; Gerrodette, 2000).

When surfacing behavior must be considered, a correction factor is used for unobserved animals, but sea turtles' dive patterns vary with size, species, ambient temperature, and activity (Lutcavage and Lutz, 1997). If a number of species are present in an area, a single correction factor for submerged (undetected) turtles could be highly biased. A major challenge is the assumption that animals are randomly distributed and can be equally sampled; abundance surveys might be designed to represent expected densities in different habitats.

Novel imaging methods developed for other fields of study have the potential for use in aerial and vessel surveys of sea turtles. They would allow both an increase in the proportion of turtles available to be counted and an increase in the recording of observed turtles in a way that would reduce detection bias. For example, vessel-mounted multibeam sonar is in use and allows imaging of individual fish within schools. The signal resolution of some systems is sufficient to estimate sizes of individual animals in decimeters at a distance of 90 m from the vessel (Lutcavage et al., unpublished data). Laser-based ranging systems (using light detection and ranging [LIDAR]) and radar-based ranging systems have also been used to detect marine animals and to image fish schools and, in principle, could detect turtles within the sampled swath (Hunter and Churnside, 1995; Brill and Lutcavage, 2001) although high costs and expensive post-processing activities have limited its use. High-resolution video and still photography coupled with attitude sensors that enable spatial referencing or georeferencing (assigning geographic coordinates to an image) are new approaches that might be used in aerial surveys. These imaging techniques allow recording of observations and estimation of size of detected targets and could be combined with computer software "trained" to recognize species differences that cannot be discerned by human observers. Integration of new technology and engineering solutions might help to overcome the current limitations of aerial surveys, namely species identification, size estimation, and presence of submerged animals. Coupled with species-specific understanding of dispersal rates, vertical behavior, and environmental associations from data-logging tagging studies, direct aerial or in-water surveys may lead to better indexes or absolute estimates of regional abundance.

Sea-turtle capture methods vary fundamentally by whether they have a measurable associated effort and whether sea turtles are the targeted species. Targeted sea-turtle capture methods with effort measured by net-soak time, tow time, and net size include use of tangle nets and trawl nets (Ehrhart and Ogren, 1999). Other targeted capture methods with variable potential for measures of effort include use of hand capture (Limpus and Reed, 1985b; Bjorndal et al., 2005; Bresette et al., 2010), dip nets (Witherington, 2002), hoop nets (Beavers and Cassano, 1996, James and Mrosovsky, 2004), and strike nets (Ehrhart and Ogren, 1999). However, some researchers have used measured effort associated with initial observation of turtles that are later captured by these methods (Leon and Diez, 1999; Witherington, 2002; Bresette et al., 2010).

Incidental capture of sea turtles may have either a measured or an uncertain effort associated with turtle captures. Captures from fisheries—including use of pound nets, trawls, gill nets, seine nets, longline hooks, and rod and reel—have various levels of recorded effort that depend on cooperation and communication with fishermen. In some cases, close relationships between researchers and fishermen allow high certainty of effort measurement (Epperly et al., 2007). In the case of power-plant entrapment, effort is measurable in terms of water flow and is constant except for occasional outages (Bresette et al., 1998).

Modeling Counts and Abundance Estimates

Data representing observed turtles are applied most often to measures of relative abundance or density by using point-count methods, strip-transect methods (Marsh and Saalfeld, 1989), or, more commonly, line-transect methods (Epperly et al., 1995b; Beavers and Ramsey, 1998), each with assumptions regarding detectability and availability (Buckland et al., 1993). Point-count methods are generally thought of as methods to approximate indexes of relative abundance and are not commonly used to estimate abundance or density. Although they have an assumption of constant proportionality between observation periods (a constant probability of detection), the methods do not allow the assumption to be tested.

The best example of modeling estimates of relative abundance on the basis of transect observations is the use of distance methods (Buckland et al., 2001; Eguchi and Gerrodette, 2009), in which observers measure the distance to each observed animal. With these methods, it is possible to model detectability of subjects and their density by using observed distances and counts, and researchers model the reduction in detection probability with distance from a transect, assuming perfect detectability on the line itself, or specify an effective strip width that includes a high proportion of observed animals. In the recent decades, there has been sufficient development of line-transect and strip-transect approaches, and a substantial body of peer-reviewed and technical literature addresses theory, analytical assumptions, and practical applications of survey design for in-water studies. Assumptions of line-transect versus strip-transect theory dictate survey protocols and sampling design, and reviews have concluded that line transects are preferred because they require fewer assumptions about detectability and use all the sightings in the analysis (Burnham et al., 1985; Marsh and Sinclair, 1989; Kenney and Shoop, in press).

CPUE is a measure of relative abundance that may involve removal of turtles from the population and may be applied in a variety of ways, including intentional capture for research and bycatch from fisheries. However, CPUE does not always have a linear relationship with density (Hilborn and Walters, 1992). Fishery studies have shown that the nonlinear function is most common in circumstances in which sea turtles are typically captured by individual research projects, namely captures of clustered animals with effort concentrated in a small spatial scale where turtles are most abundant. Sample biases, inconsistent methods between projects, and low and variable capture rates can make it difficult to justify the use of CPUE as a quantitative index of abundance statistically. However, pooling of regional capture efforts may reduce the difficulty. Within a capture project, reducing sampling bias would rely on standardization of sampling season, capture gear, and other methods that affect capture efficiency. Ideally, sampling would be randomized in space and time, especially if CPUE is to apply regionally. However, nonrandom sampling, as at individual index sites, can be valuable in assessing qualitative annual trends. The problems with the reliability of CPUE to represent relative population abundance are likely to be reduced as multiple capture projects are used within a regional meta-analysis. Although, unlike regional aerial surveys, a multiproject CPUE analysis would still rely on discrete sampling points; benefits over aerial observations would include positive species identifications and separation by sex, genetic population, and size (age).

CMR estimates of abundance are possible wherever sea turtles are captured by any method, with or without measured capture effort, as long as recapture rates are high enough (Le Gall et al., 1986; Chaloupka and Limpus, 2001). CMR also includes marking (e.g., painting) and resighting of turtles, which would not involve recapture. In addition to abundance estimates, captures and CMR modeling allow assessment of information on demographic structure and survivorship rates. Pine et al. (2003) offer a review of study designs that use CMR under a variety of assumptions and information needs.

As with CPUE from individual-capture project locations, CMR can estimate regional population abundance more powerfully if it uses multiple capture sites. CMR data collection coordinated within a networked array of sites, including nesting beaches, would provide one of the most detailed and powerful datasets possible for assessments of sea-turtle abundance and for measurement of many important demographic rates (Chaloupka and Limpus, 2001; Bjorndal et al., 2005). Wider networking of capture sites allows a wider inclusion of turtles' state variables, such as sex, genetic identity, size, physiological condition, breeding status, and geographic location.

Integrative Methods

In many cases, aerial surveys are undertaken to assess a variety of air-breathing species (e.g., Marsh and Sinclair, 1989; Palka, 2000), but their distributions and dispersal patterns may not be similar. That is especially true in foraging areas because sea birds, mammals, and sea turtles target different prey and would tend to aggregate where their food is concentrated. How well in-water surveys represent true abundance is never known, but surveys that use existing knowledge of sea-turtle dispersal rates, vertical behavior, and environmental associations better are needed. Sonic tracking and satellite telemetry can be used to provide context for interpreting surface abundance patterns and linkage between study areas (Blumenthal et al., 2006). Integrative studies that use different technologies are being applied to large pelagic fish and sharks (see Nielsen et al., 2009). For example, are habitats being used primarily for feeding, refuge, transit, nesting, or mating? Novel sensors that record behavior—such as orientation magnetometers or "daily diary" tags (e.g., Wilson et al., 2008), mouth sensors (Hochscheid et al., 2005; Myers and Hays, 2006; Fossette et al., 2008), and stomach-temperature "pills" developed by Southwood and Kirby (2008)—can detect foraging events, and GPS-satellite–linked tags provide high-resolution locations where events occur. Various behaviors have been monitored with animal-borne imaging systems (e.g., critter cams; Heithaus et al., 2002; Reina et al., 2005; Seminoff et al., 2006; Arthur et al., 2007). Acoustic arrays, video monitors, and tracking networks now deployed primarily to track marine mammals or fish species may be used to monitor behavior of sea turtles in a variety of habitats or "hotspots." Broad-scale deployment of acoustic receiver systems, such as the Ocean Tracking Network (O'Dor and Stokesbury, 2009), establishes the potential to integrate information on sea-turtle movements across state and national boundaries.

Integrated spatial and temporal information on dispersal behavior is necessary to understand and inform interpretation of abundance patterns obtained with aerial or in-water methods. In addition, oceanographic, remote-sensing, and climactic information (e.g., presence or strength of El Niño, Gulf Stream eddies, tropical depressions) provide additional context for understanding abundance patterns (Saba et al., 2008; Mansfield et al., 2009a).

In ecosystem approaches to marine-resource management, there is a new emphasis on fishery-independent surveys to provide better assessment tools and understanding (Cotter et al., 2004, 2009; Jennings, 2005). Some of the approaches include the development of indicator series of survey-based models (Rice and Rochet, 2005), which may offer good applications for sea-turtle assessment, that by tradition lack CPUE-based frameworks.

CONCLUSIONS AND RECOMMENDATIONS

Measuring Population Trends on Nesting Beaches

Conclusions:

- Choice of techniques to estimate adult-female abundance on nesting beaches has been influenced by logistics, personnel availability, opportunity, existing networks, and historical data. Few studies have sought to optimize the information gathered, given resource expenditure.
- Most U.S. nesting beaches have programs in place to count nests as a measure of sea-turtle abundance. The programs have extensive geographic coverage but do not provide direct turtle counts, measure recruitment, or estimate adult-female survival and reproductive rates. Few programs measure representative egg-to-hatchling survival.
- Multiannual near-saturation tagging of nesting females on the nesting beach provides a straightforward way to count turtles, measure recruitment, and estimate survival and reproductive rates, but the required effort is extensive and would be difficult and expensive to maintain throughout a population's range and nesting season for a statistically powerful time series.
- Seasonal nest counts require less effort per spatiotemporal unit. However, these counts estimate adult females indirectly (with associated error) and do not produce other information on vital rates.
- Interpretation of tracking data to measure reproductive rates has been used as a substitute for direct identification of large numbers of nesting females through tagging studies.

Recommendations:

• NMFS and the U.S. Fish and Wildlife Service (USFWS) should work with the states, and with other countries, to coordinate existing nesting-beach data collection so that effort is balanced between geographic scope and depth of information gathered.

• Agencies should facilitate a tiered method of nesting-female abundance counts on beaches spanning a spectrum of data scope (breadth and depth proportions). An example of such a tiered method is (1) standardized population-wide track or nest counts with spatiotemporal sampling that could detect biologically significant spatial trends; (2) nest counts in representative index locations and seasons with spatiotemporal sampling over a time series long enough to detect biologically significant spatial and annual trends (e.g., a change of 1% per year); and (3) near-saturation identification tagging in representative index locations and seasons with mark-and-recapture rates of sufficient statistical power to detect biologically significant changes in annual number of nesting females, breeding rates, recruitment, and survivorship.

• The proposed methodological tiers ideally would be divided among existing research and conservation efforts and groups. For example, beach surveyor networks coordinated by government, nonprofit, and university-organized entities, are effective in maintaining broad-scale track and nest counts for long time series. Those groups may also coordinate indexed nest counts and conduct near-saturation tagging efforts. However, extensive tagging programs may be attractive to individual researchers in consulting firms and universities because of the potential that such projects have for ancillary basic and applied research.

• Because existing datasets and data-collection networks are important in planning efforts to measure nesting-female abundance on beaches, attention should be given to coordination and training that would focus existing data collection on statistically valid and powerful sampling and methods, measurement of observational error, and the recording effort.

• NMFS, USFWS, and the states should facilitate representative sampling of nesting females tracked with satellite tags, GSM telephone tags, or other technologies to describe clutch frequency and test hypotheses on nesting-site fidelity. Those methods have a lower potential to generate survival rates than extensive marking with PIT and flipper identification tags. However, those tracking methods are useful for estimating clutch frequency in populations that nest over a broad geographic range where the mark–recaptures rate per unit effort is low. Remote tracking efforts that take place in conjunction with extensive marking of nesting turtles are recommended as a powerful combination of comparative methods.

Measuring Population Trends in the Water

Conclusions:

- Given an extensive distribution of current studies of sea turtles in the water, there is the potential for an integrated network of sampling projects to assess abundance and trends on local and regional scales.
- This integrated network would comprise intensive, low-variance measures of relative or absolute abundance in multiple, turtle-dense areas (i.e., index sites) and less-intensive, broad-scale measures of relative abundance throughout the same regions. Index sites may need to be geographically broad where turtle densities are determined by transient oceanographic features.
- Establishment and coordination of an integrated network, participant training, data sharing, and effective data management will require NMFS to provide resources, such as specialized program funding, expertise, and adequate staff.
- Assessments of relative abundance are sufficient for determination of trends; however, localized measures of absolute abundance are helpful in evaluating incidental catch and mortality and other takes.
- CMR efforts in various international locations have contributed to local and regional analyses using open robust design models to estimate relative or absolute abundance.
- Less-intensive, broad-scale measures of regional relative abundance (e.g., aerial surveys) are not a substitute for abundance measures in index sites. However, broad-scale surveys can fit into an integrated network of sampling projects by calibrating counts between well-sampled index sites and poorly sampled sites, by identifying spatial overlap with fisheries and other human activities, and by providing the only possible measure of relative abundance in inaccessible areas.
- Broad-scale measures, such as aerial surveys, may not be appropriate for estimates of regional abundance because of costs associated with long-term sampling and maintenance of extended synoptic surveys. They are most useful when coupled with measures of detectability and availability that allow estimation of turtle density.
- Measures of relative abundance based on aerial surveys will become more useful when detectability is improved by application of new technologies (e.g., LIDAR, multibeam sonar) and collection of more detailed information that would allow abundance to be assigned to specific size or ageclasses of a population's conceptual model. For example, new instrumentation, such as image mosaic and rectification, will allow accurate size assessment and help to define relationships and demographic overlap of surveyed areas and index sites where turtle life stages and genetic stocks are known.

• Fishery observer data can contribute to relative-abundance estimation when effort and vulnerability to capture (or detection) is understood (how it varies with catch rate) and when information that would allow abundance to be assigned to ageclasses of a population's conceptual model is collected.

Recommendations:

• NMFS should play a leadership role in assessments of sea-turtle abundance and trends by funding and coordinating an integrated network of sampling projects.

• Index sites should have internal (within-project) consistency in methods. Methods should be standardized between sites with similar sampling conditions but need not be standardized among all index sites.

• Random or periodic sampling in index sites is recommended to reduce sampling bias; however, consistency in bias should allow determination of representative trends in relative abundance.

• Index sites should be representative of geographic areas, genetic stocks, and life stages.

• Effective coordination should include training participants in network protocols and data reporting, application of incentives, and stipulation of requirements to achieve data sharing.

• Effective data management should include open access to data, metadata, and data products and facilitation of analyses by third parties.

• To improve its program for assessing abundance and trends, NMFS should develop a networked array of sites, having long-term CMR efforts that would support local and regional analyses with open robust-design models to estimate relative or absolute abundance specific to ageclasses in the conceptual models of populations. Assigning abundance to a conceptual model implies that turtles are identified by their genetic stock and that abundance measures apply to specific life stages. Secondarily recommended for multiple index sites are measures of relative abundance with quantified effort and estimated values for detectability, having relative-abundance measures that can be assigned to specific ageclasses of a population's conceptual model. This includes most in-water capture studies with quantified effort.

Assessment of Sea-Turtle Status and Trends

Integrating Demography and Abundance

Committee on the Review of Sea-Turtle Population Assessment Methods

Ocean Studies Board

Division on Earth and Life Studies

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Cover: The front cover images include five of the six species of sea turtles found in U.S. waters (from top to bottom and left to right): leatherback (provided by Guillaume Feuillet, Association Kwata), Kemp's ridley (provided by Selina Heppell, Oregon State University), hawksbill (provided by the National Oceanic and Atmospheric Administration), olive ridley (provided by Guillaume Feuillet, Association Kwata), and green (provided by Claire Fackler, National Oceanic and Atmospheric Administration). The back cover image is the sixth species, which is the loggerhead (provided by William Precht, National Oceanic and Atmospheric Administration).

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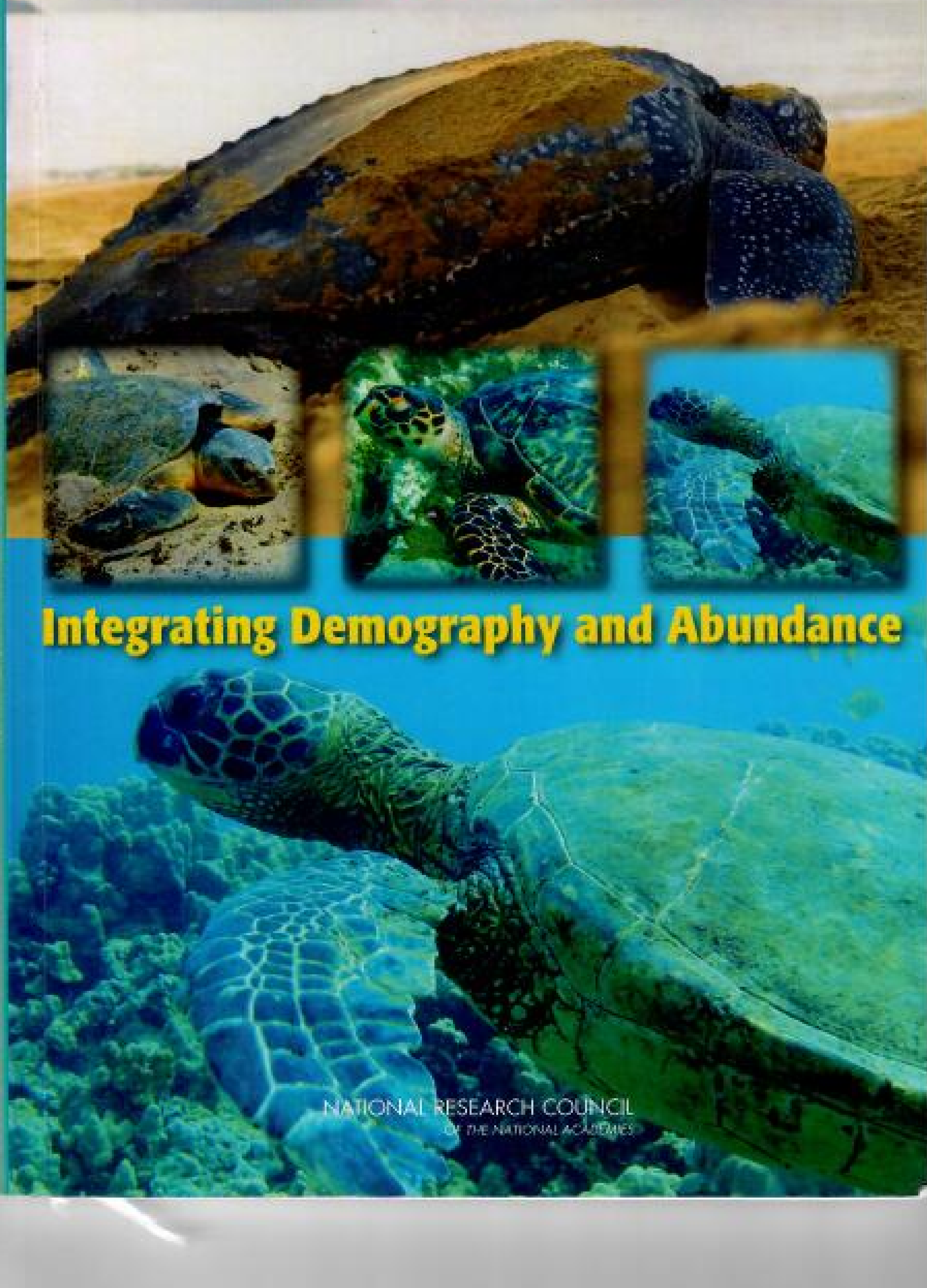

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