NOAA Technical Memorandum NMFS-SEFSC-621

PHOTO-IDENTIFICATION CAPTURE-MARK-RECAPTURE TECHNIQUES FOR ESTIMATING ABUNDANCE OF BAY, SOUND AND ESTUARY POPULATIONS OF BOTTLENOSE DOLPHINS ALONG THE U.S. EAST COAST AND GULF OF MEXICO: A WORKSHOP REPORT

BY

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September 2011

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Executive Summary
Bay, sound and estuary (BSE) populations of bottlenose dolphins are common along the U.S. Atlantic and Gulf of Mexico coasts. NOAA Fisheries currently identifies 9 BSE stocks in the Atlantic and 32 in the northern Gulf of Mexico. Accurate abundance estimates for these stocks are an essential component of MMPA-mandated stock assessment, yet only three of these BSE stocks have up-to-date abundance estimates. Abundance estimates based on data more than 8 years old are not considered valid for management (i.e., to estimate PBR) under the MMPA and those more than 5 years old drop a stock assessment from adequate to inadequate under the NOAA Fisheries Stock Assessment Improvement Plan. For most stocks in U.S. waters, aerial and/or large vessel line-transect surveys provide the platforms for abundance estimation. Line-transect "distance" analysis methods from vessels and planes are relatively well understood and these methods are more or less standardized. While line-transect surveys using small boats may be appropriate for some estuarine systems, such surveys are not suitable when working inside estuarine waters with complex topography and turbid waters. As a result, alternative methodologies have been utilized, most centered around the use of photo-identification (photo-ID) capture-mark-recapture (CMR) techniques.

However, CMR studies using photo-ID are more complex in terms of design constraints and analytical methods and do not have a well-defined "standard" approach for populations of cetaceans residing in topographically complex estuarine habitats. Furthermore, the areas inhabited by most BSE stocks often experience influxes of non-resident animals, further complicating the ability to obtain an abundance estimate for the resident stock alone. In many cases, field methods for collecting photo-ID data, definitions of residency and analytical tools are not standardized across studies of different BSE stocks. These differences in methodologies affect resulting abundance estimates and make comparison of abundance estimates and PBR calculations across different BSE stocks difficult.

The Workshop sought to develop agreed upon best practices for fieldwork, photo processing and analytical practices for estimating abundance for estuarine bottlenose dolphin populations in the Southeast United States using CMR methods. Participants first reviewed information on BSE stocks, with a focus on residency patterns. Based on this review, a definition of resident dolphin, i.e., those that should be counted for an accurate estimate of the abundance of a BSE stock, was created: residents are those individuals that spend greater than 50% of their time in a given year within a given estuary.

Next, participants reviewed field methods used recently to generate CMR abundance estimates in bottlenose dolphin populations, examined standard analytical methods for application of CMR to wild populations, and reviewed methods for photo analysis in order to generate a list of best practices for each step in the process of a photo-ID CMR study. Obtaining a reliable estimate of abundance using CMR methods requires thoughtful sampling design. Sampling design is critical to provide adequate data and avoid dilution of capture-recapture effort, assure that critical assumptions of CMR analyses, including that of population closure and adequate mixing of marked and unmarked individuals, are met, maximize capture probabilities, and deal with longer-term issues of temporary emigration/immigration. Workshop participants recommended use of the Robust Design when planning photo-ID CMR studies. By following a Robust Design (e.g., seasonally spaced primary sampling sessions comprised of multiple, quick secondary

sessions), robust estimates of resident animals can be obtained. Additional considerations for the use of natural marks, temporal and geographic allocation of survey effort, and sample size that would be meet assumptions necessary in CMR analysis were also discussed.

Photographs of dorsal fins are the raw data from which estimates of abundance of bottlenose dolphins using photo-ID CMR methods are generated. Photos are acquired through field surveys. Surveys must be conducted in appropriate weather conditions and with proper attention to the safety of both dolphins and field crews. Best practices for fieldwork, particularly what not to do when working with a dolphin group, were compiled. In addition, considerations for field data collection, how to best photograph dolphins in an encounter, environmental data to record, and appropriate metadata to collect were documented.

Following field surveys, all photographs must be processed. Obtaining good quality images of dorsal fins is of paramount importance to obtaining an unbiased estimate of abundance using photo-ID CMR methods. Two parameters of utmost importance are image quality and fin distinctiveness. Only high quality images of distinctive fins should be used in a CMR analysis. Participants recommended criteria for scoring image quality and fin distinctiveness as well as guidelines for photo matching, metadata and archiving.

Finally, CMR analysis methods were discussed. Appropriate modeling is needed to address sources of variation that cannot be dealt with in sampling design, to produce unbiased estimates of abundance and efficiently accommodate complex datasets. For bottlenose dolphins, the problem of temporary immigration/emigration of non-residents is significant, as it is clear that most BSE stocks experience short-term visits from members of adjacent coastal or BSE stocks. Current analysis software does not provide a means to analyze data from the Robust Design to account for non-resident animals but such models are under development. Careful survey design must be incorporated if non-resident animals are suspected to regularly enter the range of a BSE stock. In addition, abundance estimates must be corrected for the proportion of unmarked animals in the population. Workshop participants agreed that careful thought must be given to both of these aspects of a CMR abundance estimate. Addressing them adequately requires specific survey design plans and photographic effort and participants discussed a variety of points that must be considered when performing a CMR analysis.

Abundance estimates are a critical component of assessing the status of stocks of marine mammals in U.S. waters. Obtaining estimates for BSE stocks of bottlenose dolphins is arguably less straightforward than for many of the other stocks that inhabit more open water environments. As a final step, workshop participants generated a list of best practices for each step in the process of using photo-ID based CMR methods to estimate abundance: survey design, field work, photo analysis and matching, CMR analysis. Implementation of these practices in future studies provides a means to obtain robust abundance estimates as well as estimates that are comparable across different BSE stocks. In turn, PBR estimates for these stocks can then be based on equivalent methodologies for data collection and analysis, which will greatly improve consistency in assessing status for these BSE stocks. There is still room for improvement in some aspects of this process and a summary of future needs was created. One of these, a workshop to standardize steps in photo-analysis is already planned for the 18th Biennial Conference on the Biology of Marine Mammals to be held in November 2011.

Table of Contents

EXECUTIVE SUMMARY .... **iii**

BACKGROUND **1**

WORKSHOP GOALS **2**

SHORT HISTORY OF BOTTLENOSE DOLPHIN BAY, SOUND AND ESTUARY STOCKS IN THE SOUTHEAST UNITED STATES **2**

Evidence for resident populations 3

Abundance estimates 6

Residents versus non-residents 7

DEFINING RESIDENTS FOR ABUNDANCE ESTIMATION FOR CONSERVATION AND MANAGEMENT PURPOSES **7**

GENERAL CONSIDERATIONS FOR CMR ABUNDANCE ESTIMATION **8**

Residents versus non-residents 10

GENERAL CONSIDERATIONS FOR FIELD SAMPLING DESIGN **10**

GENERAL CONSIDERATION FOR PHOTO ANALYSIS **11**

BEST PRACTICES **13**

Survey design 13

Field work 14

Photo analysis and matching 16

CMR analysis 17

FUTURE WORK **18**

Photo-analysis 18

CMR analysis 19

Other Recommendations 19

APPENDIX I. SIZES OF GULF OF MEXICO BAY, SOUND AND ESTUARY AREAS (COMPILED FROM GULFBASE.ORG). **21**

APPENDIX II. MEASUREMENT OF PHOTOGRAPHIC QUALITY AND DOLPHIN DISTINCTIVENESS FOR THE MID-ATLANTIC BOTTLENOSE DOLPHIN PHOTO-ID CATALOG. KIM URIAN, CURATOR **22**

LITERATURE CITED **24**

WORKSHOP AGENDA **28**

LIST OF WORKSHOP PARTICIPANTS **30**

Acknowledgments

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Background

Common bottlenose dolphins, *Tursiops truncatus*, are abundant in offshore, coastal and estuarine habitats of the U.S. East Coast and Gulf of Mexico. The species is protected under the Marine Mammal Protection Act (MMPA) of 1972 where the basic unit of protection is the "population stock." Under the MMPA, a population stock is defined as "a group of marine mammals of the same species or smaller taxa in a common spatial arrangement, that interbreed when mature." Since 1972, several additional documents have further clarified this definition. NMFS (2005) states that a stock should be recognized as a demographically independent population in which the internal population dynamic processes of births and deaths are more important to the cohesiveness of the population than external dynamics of immigration and emigration. The original MMPA definition of stock is equivalent to the definition of a biological population under an evolutionary paradigm (Waples & Gaggiotti 2006), while the 2005 refinements shift the definition of stock towards an ecological time frame. The terms stock and population will be used interchangeably in this document.

Under the MMPA, the status of each stock must be assessed regularly. A primary component of the assessment is calculation of the annual potential biological removal (PBR) level for each stock. Because abundance estimates are an integral part of PBR calculations (Wade & Angliss 1997), an accurate estimate of abundance is a critical component of each stock assessment. Most bay, sound and estuary (BSE) populations of bottlenose dolphins along the U.S. East Coast and Gulf of Mexico either lack abundance estimates, or have estimates that are inadequate and/or out of date (Waring *et al*. 2010). Many of these populations experience significant anthropogenic impacts, as they inhabit nearshore, estuarine waters adjacent to areas of high and/or growing human population density. As a result, there is an immediate need for accurate and up-to-date abundance estimates for these stocks. However, typical methods for estimating cetacean abundance, such as line-transect visual surveys by air or by large vessel (Buckland *et al*. 1993; Buckland *et al*. 2001), are not easily implemented in most BSE environments because they are small and topographically complex interfering with standard line-transect design, and murky waters and submerged aquatic vegetation reduce the ability to sight dolphins from aircraft. In addition, these methods do not provide the ancillary information needed to determine if individual dolphins are resident members of a given stock. As a result, researchers have in recent years, turned to the use of photo-identification (photo-ID) based capture-mark-recapture (CMR) methods for abundance estimation (Balmer *et al*. 2008; Conn *et al*. 2011; Read *et al*. 2003; Speakman *et al*. 2011). However, comparability of CMR estimates can be compromised due to differences in field and/or analytical methods across studies. For example, survey design and season of sampling and corrections for unmarked fins can vary across published studies as can accounting for non-resident animals that visit the area rarely. This variability creates difficulties in comparing and ensuring consistency in abundance estimates across BSE stocks. Because these estimates are used in the calculation of PBR for management purposes, it is important that they are comparable from one stock to the next. Thus, there is a need for a suite of best practices for estimating abundance using photo-ID CMR that can be applied consistently across all BSE stocks.

Workshop Goals

The primary goal of this workshop was to create a set of best practices for survey design, field work, photo analysis, and statistical analysis such that CMR abundance estimates generated for BSE populations would be robust and suitable for managing the populations over long periods of time, suitable for resultant calculations of PBR, and provide assessments that are comparable across all BSE populations of bottlenose dolphins along the U.S. Atlantic coast and Gulf of Mexico. Workshop participants recognized that the guidelines must address a variety of complications posed by BSE bottlenose dolphin populations, including a) Whom to count: how to address presence of non-resident animals and how to account for unmarked (i.e., animals without distinctive markings) resident dolphins; b) When to count: how to address seasonal changes in habitat usage within a BSE area; and c) Where to count: how to address potential overlap in habitat usage by adjacent coastal and BSE stocks. Such guidelines must also be flexible enough to remain applicable across the varied and complex topographies presented by the different BSE habitats and the varied habitat usage patterns seen in bottlenose dolphins throughout the region. To develop these guidelines, the Workshop first reviewed information on BSE stocks, with a focus on residency patterns and then defined what animals should be included, reviewed field methods used recently to generate CMR abundance estimates in several bottlenose dolphin populations, examined standard analytical methods for application of CMR to wild populations, and reviewed methods for photo analysis.

Short History of Bottlenose Dolphin Bay, Sound and Estuary Stocks in the Southeast United States

Bottlenose dolphins living in bay, sound and estuarine waters of the East Coast and Gulf of Mexico have been treated unevenly under the MMPA stock assessment report process. The first delineation of marine mammal stocks within U.S. waters began with the 1994 amendments to the MMPA. At that time, 33 different stocks were identified across Gulf of Mexico BSE habitats, ranging from the Florida Keys across the northern Gulf and west and south to the U.S. – Mexico border (Fig. 1) while today there are 32 recognized stocks, as Sarasota and Little Sarasota Bays have been combined (Waring *et al*. 2010). The original basis for delimiting stocks in each of the distinct BSE habitats along the Gulf Coast lay in results from long-term studies of bottlenose dolphins in Sarasota Bay, Florida and Matagorda-Espiritu Santo Bay and Aransas Pass, Texas, all of which provided evidence for long-term, multi-year residency by dolphins in these areas (Gruber 1981; Scott *et al*. 1990; Shane 1980; Wells *et al*. 1987).

Evidence for similar resident populations in estuarine waters along the U.S East Coast was limited at the time. Therefore, the first stock delineation in 1995 for Atlantic nearshore bottlenose dolphins defined a single coastal stock that ranged from New York to Florida. The range of this stock included only coastal waters out to the shelf break. Dolphins inhabiting estuarine waters were not included in stock assessment reports until 2009 when new BSE stocks were delineated in the Atlantic (Waring *et al*. 2010). Currently, 9 BSE stocks are recognized along the U.S. East Coast (Figure 2), and the original single coastal stock has now been divided into 5 separate coastal stocks (Waring *et al*. 2010).

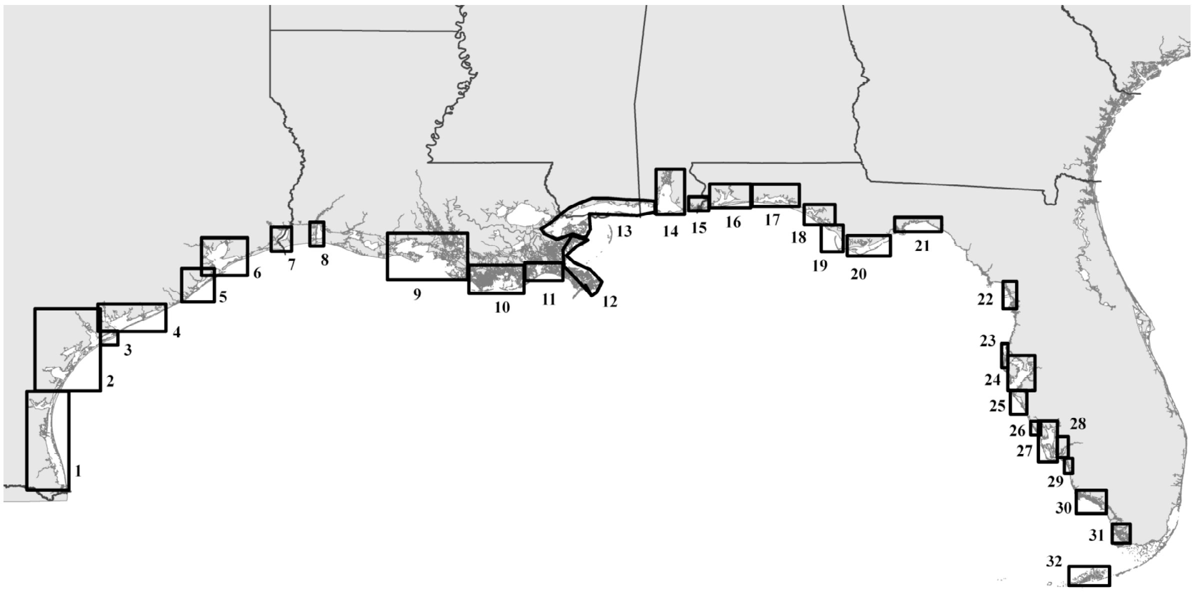

Figure 1. Approximate stock areas for each recognized BSE bottlenose dolphin stock in the northern Gulf of Mexico. 1- Laguna Madre, 2- Corpus Christi and surrounding bays, 3- Espiritu Santo and Redfish Bay, 4- Matagorda and surrounding bays, 5- West Bay, 6- Galveston Bay, 7- Sabine Pass, 8- Calcasieu Lake, 9- Vermilion to Atchafalaya Bay, 10- Terrebonne and Timbalier Bays, 11- Barataria Bay, 12- Mississippi River Delta, 13- Mississippi Sound, Lake Borgne, Bay Boudreau, 14- Mobile Bay, 15- Perdido Bay, 16- Pensacola Bay, 17- Choctawhatchee Bay, 18- St. Andrew Bay, 19- St. Joseph Bay, 20-St. Vincent Sound & Apalachicola Bay, 21- Apalachee Bay, 22- Waccasassa Bay to Crystal Bay, 23- St. Joseph Sound & Clearwater Harbor, 24- Tampa Bay, 25- Sarasota Bay & Little Sarasota Bay, 26- Lemon Bay, 27- Charlotte Harbor, Gasparilla Sound & Pine Island Sound, 28- Caloosahatchee River, 29- Estero Bay, 30- Chokoloskee Bay to Gullivan Bay, 31 Whitewater Bay, 32- Florida Keys.

The BSE habitats utilized by these stocks in the Atlantic and Gulf of Mexico are quite variable in size, shape, average water depth, and topographic complexity (Appendix I). For example, some bays, such as Choctawhatchee Bay, FL are larger areas of primarily open water, nearly fully enclosed with one or two small openings to adjacent coastal waters. Others, like the Charleston, SC area or estuarine areas along the coast of Texas, are comprised of complex estuarine habitats (i.e., salt marsh intersected by smaller tributaries and larger rivers and with varying tidal flux). This environmental variability is an important characteristic that plays a vital role in developing comparable CMR research techniques across BSE habitats.

Evidence for resident populations

Since the mid-1990's, significant progress has been made in our understanding of residency patterns of bottlenose dolphins in bays, sounds and estuaries of both the Gulf of Mexico and the Atlantic. These studies have solidified the picture of multiple, small populations that show strong site fidelity to a given BSE environment with limited genetic exchange among sites. Many of these populations exhibit significant genetic differentiation (Litz *et al*. in press; Rosel *et al*. 2009; Sellas *et al*. 2005) indicative of true populations that are demographically independent. In Sarasota Bay, FL 40 years of tagging, tracking and photo-ID work have revealed multi-decadal, multi-generational year-round residency in a population of approximately 160 individuals (Wells 2009). Many individuals seen over the past few decades show striking fidelity to the area, a pattern that appears to be created in early life stages as juveniles tend to show natal philopatry (McHugh 2010). Within Sarasota Bay, non-resident animals are seen, but there is little evidence for long-term mixing of residents and non-residents. Only 14-17% of sightings of Sarasota Bay residents include non-residents and when mixed groups are seen, they tend to be present offshore of the passes that link Sarasota Bay to adjacent coastal waters (Fazioli *et al*. 2006). Similar long-term residency patterns are documented in both Tampa Bay, FL to the north (Urian *et al*. 2009; Wells *et al*. 1996b) and Charlotte Harbor/Pine Island Sound, FL to the south (Wells et al. 1996a). Site fidelity to these areas has been maintained despite rapid coastal development, harmful algal blooms (McHugh *et al*. 2011) which result in significant alteration of prey abundance (Gannon *et al*. 2009) and potential changes in dolphin health, and hurricanes (Wells 2010).

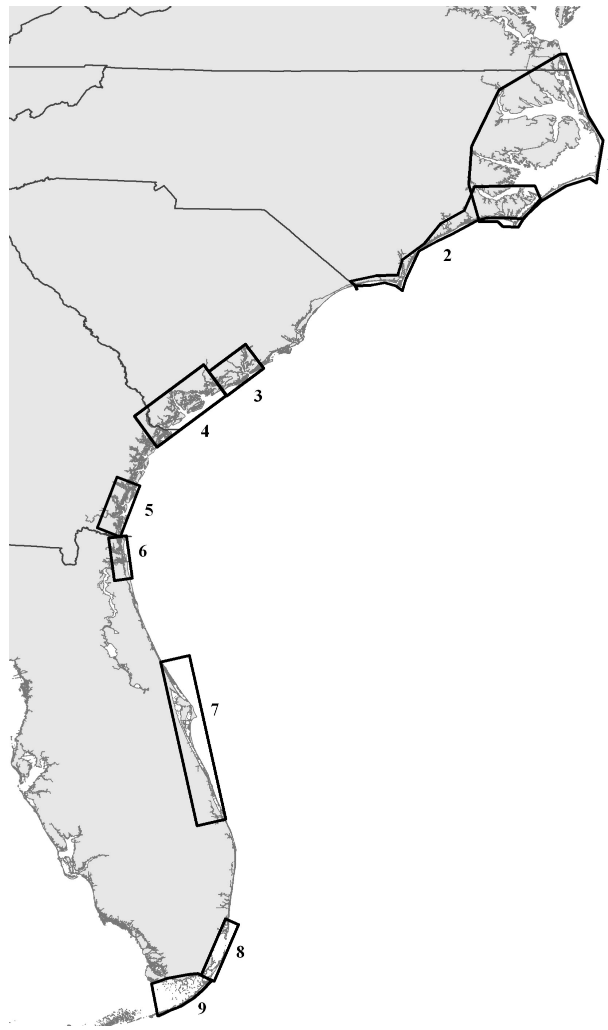

Figure 2. Approximate stock areas for each recognized BSE bottlenose dolphin stock in the Atlantic. 1-Northern North Carolina Estuarine System, 2-Southern North Carolina Estuarine System, 3-Charleston Estuarine System, 4- Southern South Carolina/Northern Georgia Estuarine System, 5- Southern Georgia Estuarine System, 6- Jacksonville Estuarine System, 7-Indian River Lagoon Estuarine System, 8-Biscayne Bay, 9- Florida Bay

Studies throughout the Gulf and along the U. S. East Coast have revealed similar patterns of year-round, multi-year residency (Table 1). For example, using both radio-telemetry and photo-ID CMR data, Balmer *et al*. (2008) examined residency patterns of bottlenose dolphins in St. Joseph Bay, FL between 2005 and 2007 and found support for the existence of a resident population and evidence for an annual, seasonal influx of animals from outside St. Joseph Bay. Along the Atlantic coast, some of the earliest evidence for resident estuarine populations came from the Indian and Banana Rivers in central Florida (Odell & Asper 1990). Zolman (2002) was one of the first to document a multi-year, year-round resident estuarine population north of Florida along the Atlantic coast and since then residency has been documented in multiple estuarine areas from Jacksonville, FL (Caldwell 2001) to central North Carolina (Read *et al*. 2003) (Table 1). No evidence for year-round, multi-year residency has yet been found for regions north of North Carolina.

Table 1. Summary of evidence for bottlenose dolphin residency in BSE habitats along the U.S. East Coast and Gulf of Mexico. (**Y**es/**N**o/**U**nknown)

Site	Residents?	Year-Round?	Multi-Year?	Non-resident Pulses?	Source
Gulf of Mexico					
Aransas Pass, TX	Y	Y	Y	Y	(Shane 1977; 1980)
Matagorda Bay, TX	Y	Y	Y	Y	(Gruber 1981; Lynn 1995)
San Luis Pass, TX	Y (Bay)	Y (Bay)	Y (Bay)	N (Bay)	(Henderson & Würsig 2007; Maze & Würsig 1999)
Galveston, TX	Y	Y	Y	Y	(Fertl 1994; Irwin & Würsig 2004; Maze & Würsig 1999; Maze-Foley & Würsig 2002)
Barataria Bay, LA	Y	?	?	Y	(Miller 2003)
Chandeleur Sound, LA	U	U	U	Y	(Mullin 1988)
Mississippi Sound, MS	Y	Y	Y	Y	(Hubard *et al.* 2004)
Wolf Bay, AL	Y	Y	Y	Y	(Pabody 2008)
Pensacola Bay, FL	Y	Y	Y	Y	S. Shippee pers. comm.
Choctawhatchee, FL	Y	Y	Y	Y	S. Shippee pers. comm.
Panama City, FL	Y	Y	Y	Y	(Bouveroux & Mallefet 2010)
St. Joseph Bay, FL	Y	Y	Y	Y	(Balmer *et al.* 2008)
Apalachicola Bay, FL	Y	U	U	Y	(Tyson 2008)
Cedar Keys, FL	Y	Y	U	Y	(Quintana-Rizzo & Wells 2001)
Tampa Bay, FL	Y	Y	Y	U	(Urian *et al.* 2009; Wells *et al.* 1996b)
Sarasota Bay, FL	Y	Y	Y	N	(Wells 2003)
Lemon Bay, FL	Y	Y	Y	N?	(Bassos-Hull *et al.* In review).
Charlotte Harbor, Pine Island Sound FL	Y	Y	Y	N?	(Bassos-Hull *et al.* In review; Wells *et al.* 1996a)
Florida Keys, FL	Y	U	Y	U	L. Engleby pers. comm.
Western North Atlantic					
Florida Bay, FL	Y	Y	Y	U	L. Engleby pers. comm.
Biscayne Bay, FL	Y	Y	Y	N	(Litz *et al.* in press)
Indian River Lagoon, FL	Y	Y	Y	N	(Mazzoil *et al.* 2008; Odell & Asper 1990)
Jacksonville, FL	Y	N	Y	Y	(Caldwell 2001)
Brunswick, GA, Sapelo, GA	Y	Y	Y	Y	(Balmer 2011)
Savannah, GA	Y	Y	Y	Y	T. Cox & R. Perrtree pers. comm
Calibogue Sound, SC	Y	Y	Y	Y	(Gubbins 2002)
Charleston, SC	Y	Y	Y	Y	(Speakman *et al.* 2011; Zolman 2002)
Cape Romain, SC	Y	Y	Y	Y	(Sloan 2006)
Pamlico Sound, NC	Y	Y	Y	N	K. Urian pers. comm…

Abundance estimates

Abundance estimates are a critical component of marine mammal stock assessments. A population size estimate is required for the calculation of PBR, defined as "the maximum number of animals, not including natural mortalities that may be removed from a marine mammal stock while allowing that stock to reach or maintain its optimum sustainable population." The 20th percentile of the sampling distribution of the abundance estimate (e.g., the lower bounds of a one-sided 80% confidence interval) is used in the PBR calculation, thereby providing some buffer against uncertainty in the abundance estimate (Wade 1998). For BSE populations, abundance estimates have been obtained using a variety of methods. In the Gulf of Mexico, estimates for many stocks were originally obtained using standard line-transect visual survey data collected from fixed-wing aircraft in 1992-1993 (Blaylock & Hoggard 1994; Waring *et al*. 2010). Line-transect survey methods provide an estimate of the total number of dolphins present at the time of the survey with no distinction between residents and non-residents. Aerial surveys are not generally effective for surveying smaller bodies of water, areas of complex estuarine habitat or regions with turbid water. For example, the 1992-1993 aerial surveys sighted no dolphins (producing an abundance estimate of zero) in areas where boat-based surveys have since produced estimates of 100 or more dolphins (e.g., St. Joseph Bay). In some areas, population size has been estimated as a direct count of known, identified residents (e.g., Sarasota Bay: (Wells 2009) and in others, small-vessel line-transect methods have been used (Mullin *et al*. 1990). Small-vessel based line-transect surveys are appropriate for some BSE stocks, primarily those inhabiting less complex, open bodies of waters, but do not provide a means to separate resident from non-resident animals.

More recently, CMR methodologies using distinct dorsal fin markings as the “mark” have been used to estimate bottlenose dolphin abundance and these studies have incorporated varied survey design and sampling interval strategies (Balmer *et al*. 2008; Conn *et al*. 2011; Gubbins *et al*. 2003; Read *et al*. 2003; Speakman *et al*. 2011; Tyson 2008). For example, within the Gulf of Mexico, Balmer *et al*. (2008) used photo-ID CMR to estimate bottlenose dolphin abundance in St. Joseph Bay and adjacent coastal waters where residents have been identified. They performed surveys in multiple seasons across 3 years to obtain seasonal estimates of abundance. Tracklines within St. Joseph Bay were spaced 1km apart. Two surveys (each survey completed all tracklines within the study area) per season were conducted and each survey was completed on average in 4.1 ±0.8 SD days, with mark and recapture periods separated on average by 1.2 ± 0.4SD days. Tyson (2008) estimated abundance for the Alligator Bay- St. Vincent Sound area just east of St. Joseph Bay. For this study, surveys were performed in two seasons, summer and winter, with two passes per season and tracklines spaced 2km apart. In the Atlantic, Read *et al*. (2003) conducted two week-long surveys in Pamlico Sound, NC in summer 2000. Surveys were separated by 8 days. Here, rather than following predefined tracklines, surveys were directed to areas of expected or reported dolphin presence. Gubbins *et al*. (2003) provided abundance estimates at four sites along the U.S. East Coast (including some non-estuarine habitats). They used photo-ID sighting records of all identifiable individuals photographed during surveys conducted over a 6 month period in 1997 to obtain a minimum estimate of abundance. More recently, Speakman *et al*. (2011) conducted intensive, systematic bi-monthly surveys from 2004 to 2006 in 4 largely contiguous regions within the estuarine and coastal waters of Charleston, SC using pre-defined transect lines. Bi-monthly surveys of all 4 regions generally required 2 weeks of survey effort with a minimum of 1 week between the 2 survey sessions per each bimonthly period.

Residents versus non-residents
One of the greatest difficulties in obtaining a robust abundance estimate for management of BSE stocks of bottlenose dolphins is determining which dolphins seen during surveys should be considered a part of the stock under study - distinguishing resident and non-resident (often termed transient) individuals within the delimited BSE stock boundaries. Different stocks appear to have different patterns of use by non-resident individuals. For example, in Charleston, SC and in St. Joseph Bay, FL. influxes of non-resident dolphins appear to take place in fall (Balmer *et al*. 2008; Speakman *et al*. 2011; Zolman 2002). Seasonal residents, defined as identifiable animals that appear on a seasonal basis (i.e., every winter or every fall) over multiple years have been documented in some areas (Balmer *et al*. 2008). Furthermore, many stock areas experience visits from single, identifiable individuals that are never seen again. These are often interpreted to be animals of the adjacent coastal stock that have come into the estuary briefly and then returned to coastal waters. For other stocks, such as the Indian River Lagoon Estuarine System Stock, there is little evidence for the presence of visits from non-resident dolphins (Mazzoil *et al*. 2011)

Defining Residents for Abundance Estimation for Conservation and Management Purposes
Given the broad variation in the use of CMR methods for estimating abundance for BSE stocks, workshop participants agreed that it would be useful to define which members of a BSE stock should be considered when estimating abundance for these stocks. It was agreed that non-resident animals are not considered members of BSE stocks and in general should not be included in abundance estimates. However, distinguishing residents from non-residents can be very difficult, especially for stocks in areas lacking long-term studies. Workshop participants discussed a variety of ways to define which animals should be considered residents of a given stock and arrived at the following consensus:

> *Within an estuarine stock area, ideally the objective is to estimate the abundance of the population that primarily occupies that area, where the population is defined by the MMPA as a group of animals in common spatial arrangement that interbreeds when mature, and this has further been interpreted to be a demographically isolated biological population. Without perfect knowledge about exactly what the demographic population is, an operational objective for estimating the abundance of the estuarine stock is to estimate the abundance of the resident animals that are in that area year-round (or near year-round). It is acknowledged that this can be complicated by at least two factors: (1) that members of the population may occasionally leave the estuarine stock area (such as moving into coastal areas, or moving temporarily into an adjacent estuarine stock area), and (2) members of coastal or seasonal migratory stocks may occasionally move into the estuarine stock area. It was acknowledged that defining the "resident population" is complicated. It was agreed that a practical definition for the "resident population" would be individuals that spend greater than 50% of their time in an estuary in a given year*.

General Considerations for CMR Abundance Estimation

Direct counts of the total number of dolphins in a population to generate an absolute abundance is not possible except under rare circumstances where long-term, year-round studies of well-marked animals are conducted (Wells 2009). Therefore, it is necessary in most cases to rely on an estimate of the abundance, one that ideally is as robust as possible. Capture mark-recapture methods have been used for estimating abundance of vertebrate populations for several decades (Williams *et al*. 2002) and more recently for bottlenose dolphin populations (Balmer *et al*. 2008; Conn *et al*. 2011; Read *et al*. 2003; Speakman *et al*. 2011; Tyson 2008; Wells & Scott 1990).

In its simplest form, CMR survey design involves conducting two sampling sessions in relatively quick succession and estimates of abundance are obtained using a Lincoln-Petersen model (Chapman 1951; Seber 1982). In the first session, animals are (typically uniquely) marked, either physically or through identification of unique natural markings. Animals are "released" back into the population, allowed to mix and then a 2^{nd} field session is conducted to resample the population. The number of animals initially marked and the marked fraction in the second sample lead to estimates of abundance. However, several critical assumptions must be met to obtain an unbiased estimate of abundance (Box 1) and the estimates of abundance can be quite sensitive to violations of these assumptions (Williams *et al*. 2002).

Box 1. Standard CMR Assumptions for Estimating Abundance
Populations are spatially and demographically closed
Either batch or individual marks applied so that the capture history (when an animal was detected or not detected over the sampling occasions) can be determined
All individuals have independent and identical capture probabilities in each session and marked and unmarked animals mix.
Marks (tags) are unique, neither lost, gained nor modified, are read without error and are all equally distinctive and detectable

Of critical importance is meeting the assumption that the population is spatially (immigration/emigration) and demographically (births/deaths) closed during the period of the study. Thus, timing and duration of the study must be carefully considered. For bottlenose dolphin populations, tag loss is unlikely to occur as studies have shown that, over short study periods, natural dorsal fin marks are reasonably stable (Wilson *et al*. 1999). However, failure of marked and unmarked animals to mix and heterogeneity in capture probabilities among animals within a session can be problematic with BSE dolphin populations (Box 2). Social behavior that results in animals being non-randomly distributed or unlikely to mix with other groups in the short term may violate the assumption of complete mixing of the population between sessions. Behavioral responses such as "trap happy" (i.e., likely to be recaptured more frequently than others) or "trap shy" (i.e. recaptured less frequently) result in heterogeneity of individual capture probabilities, which can lead to severely biased estimates of abundance (Williams *et al*. 2002). The estimate does not distinguish between resident and visiting animals in the population. In addition, the simple two-session sampling design does not provide enough information to correct for biases caused by heterogeneity or behaviour effects.

Box 2. Common CMR Violations and Impact on Abundance Estimate	
Heterogeneity in capture probabilities unrelated to capture	Underestimate
Behavioral effects (trap happy/trap shy)	Under/Overestimate
Tag loss	Overestimate

Not unexpectedly, more recapture sessions can provide more precise estimates of abundance and one can deal with violations of assumptions concerning capture probabilities inherent in the Lincoln-Petersen model. For example, with 3 or more sampling sessions, more complex mathematical models (Otis *et al*. 1978) can be applied to account for variation in capture probability (such as behavioral responses, temporal effects, and individual heterogeneity) and adjust the estimate of abundance. Of the sources of variation in detection probability, heterogeneity is the most data hungry, and may require 5 or more sampling sessions to detect (Conn *et al*. 2006). However, violations of a closed system may occur with this more temporally dispersed sampling scheme and it may be necessary to use open population models such as the Jolly-Seber model (Jolly 1965; Seber 1965). However, Jolly-Seber-type open population models still may not be suitable for estimating abundance in BSE population as these models do not have a means to deal with temporary emigration, i.e., non-residents that "visit" the population, and estimates of abundance tend to be sensitive to capture heterogeneity and behavioral effects (Williams *et al*. 2002).

In order to maintain "closed" population assumptions it is necessary compress the period of time over which sampling occurs. The disadvantage of this requirement is that it cannot provide for an analysis of seasonal losses or gains. The robust design (Pollock 1982) is a significant improvement and is the recommended approach for long term monitoring studies of bottlenose dolphin BSE populations. The robust design combines both open and closed population models (Figure 3) and can provide estimates of abundance, survival, immigration and emigration. It also provides estimates of abundance that are more robust to capture heterogeneity (Clavel *et al*. 2008; Hines *et al*. 2003). The robust design uses sampling over two temporal scales. Primary periods are periods of sampling temporally spaced over a time frame in which the population may be considered open (i.e., gains and losses may occur) and secondary periods, conducted within the primary periods, are short-term sampling over which the population is considered closed. Survival may be estimated using the primary periods and abundance can be estimated using closed CMR models over the shorter periods when the population is considered closed. Combining estimates across periods allows one to estimate temporary emigration probabilities. The commonly used Program MARK (White & Burnham

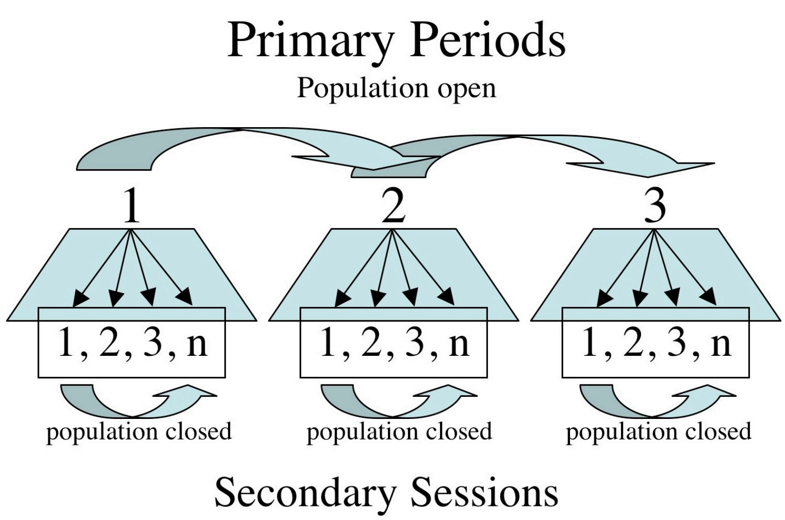

Figure 3. Schematic of robust design with three primary periods across which the sampled population is considered open and "n" secondary sessions within each primary period. The population is considered closed within each secondary session, but temporary emigration/immigration may occur between primary periods

1999) takes a likelihood approach to this method, using data from both primary and secondary periods. Use of the robust design method is strongly recommended over designs with fewer, more temporally dispersed sampling sessions because it allows the assumption of a closed population to be met through use of the secondary periods of temporally concentrated effort.

Residents versus non-residents

While models currently implemented in Program MARK (or RMARK) can account for temporary immigration/emigration they have not been sufficiently adapted to account for dolphins that use an area for a brief period but then leave and never return, or at least do not return within the time period that surveys are conducted. In particular, the presence of such non-resident dolphins in a stock area during the secondary sampling sessions violates the assumption of the closed population models currently available in MARK. Conn *et al*. (2011) developed new approaches to using CMR data to estimate abundance in the presence of such transient dolphins. One approach, following Pradel *et al*. (1997) addresses animals seen a single time during multiple sampling sessions. Such animals are most likely non-residents but the model must incorporate the possibility that animals seen only once may also be residents who just happened to be seen only once. Under this "one sample availability" model, one can obtain an abundance estimate for residents and for the total number of animals that were using the survey area during the study (Conn et al. 2011). A second approach, the "multi-sample availability" approach, allows flexibility to screen out individuals seen 2, 3, or more times. This approach provides an estimate only of the abundance of residents (Conn et al. 2011). Future work will focus on "robustifying" models that handle non-residents to include both primary and secondary sampling periods. Ideally, these models would be incorporated into popular software packages such as MARK or RMARK.

General Considerations for Field Sampling Design

There are several aspects of study design that should be considered for any CMR study.

1. First, **temporal allocation of field effort** must be carefully considered. To maintain a closed population, it is important to avoid any periods when there may be significant loss or gain of individuals, e.g., when individuals are migrating. Furthermore, the duration of each sampling session should be kept short to ensure closure. However, durations must be long enough to generate a reasonable number of captures and recaptures and the resampling periods must be sufficiently separated to allow full mixing of the population. By following a robust design of closely spaced secondary periods nested within more temporally spaced primary periods, violating the assumption of population closure can be minimized or avoided altogether.

2. A second consideration of the study design is the **spatial allocation of sampling effort**. The geographic area covered must ensure that sampling of the population is representative of the target population and at the same time that the capture and recapture samples are in fact from the same population. If the area covered is too small, there is the risk of violating the assumption of geographic closure and bias will be introduced if animals move into or away from the designated survey area between sessions. If the area covered is too large and can't be surveyed in a concise fashion, then sampling effort is thinly spread and diluted, making it more difficult to obtain a sufficient number of recaptures.

3. Thirdly, one must consider **sample size**. The number of recaptures of previously marked animals is the primary determinant of the precision of an abundance estimate. The basic determinants of the number of recaptures of marked individuals are the actual abundance, capture probabilities, and the number of sampling occasions (capture effort). Capture probabilities may be affected by several factors including animal behavior, environmental conditions and effort. Higher capture probabilities improve abundance estimates by reducing impacts of capture heterogeneity, and they also improve the ability to model and account for other sources of heterogeneity. Capture effort (i.e., the number of hours spent in the field, and the number of capture occasions) is one of the most readily controlled variables in a study design. Capture effort can be increased by intensifying survey effort, (i.e., increasing the number of tracklines covered in a session, and/or increasing the number of passes for a given session). If marked and unmarked animals truly mix across the survey area, then effort may also be more heavily weighted towards areas expected to have higher animal density, e.g., near the shoreline versus the center of a bay.

4. Lastly, it is important to consider **problems inherent in using natural marks**. Not all animals have unique natural marks. Therefore, to obtain an abundance estimate for the entire population, it is necessary to obtain an estimate of the proportion of unmarked individuals in the population, and then apply this correction outside of the typical CMR model. In addition, CMR models assume the marks do not evolve. Tag evolution, where the natural marks change over time (e.g., addition of new fin notches) leads to previously "marked" animals "disappearing" and the introduction of a "new" animal into the population. If the time frame of the overall study is long (e.g., years), this could be an important source of bias. Finally, CMR assumes that tags are read without error and corrections for false negatives (failing to identify a match) should be considered.

In summary, obtaining a reliable estimate of abundance using CMR methods requires thoughtful sampling design and model-based inference. Sampling design is critical to provide adequate data and avoid dilution of effort, assure that critical assumptions of population closure and adequate mixing of marked and unmarked individuals are met and deal with longer-term issues of temporary emigration/immigration. Appropriate modeling is needed to address sources of variation that cannot be dealt with in sampling design, produce unbiased estimates of abundance and efficiently accommodate complex datasets. For estimates of bottlenose dolphin abundances, the problem of temporary immigration/emigration of non-residents is significant, as it is clear that most BSE stocks experience short-term visits from members of the adjacent coastal stock or adjacent BSE stocks. By following a Robust Design, (e.g., sampling in several quick passes, waiting several months and then doing another set of quick passes), more information about non-resident animals can be obtained which cannot be obtained if 4 more evenly dispersed surveys are performed. Optimal survey designs are further discussed in the guidelines section.

General Consideration for Photo Analysis

Use of photos of bottlenose dolphin dorsal fins to identify individual animals dates back to two seminal papers- Würsig and Würsig (1977) and Wells *et al.* (1980). The field has grown and evolved since then, embracing new photographic technologies- black and white to color slide film, and then on to digital photography (Markowitz *et al*. 2003; Mazzoil *et al*. 2004; Würsig & Jefferson 1990) - and improving techniques and software for photo analysis and matching of fins (Adams *et al*. 2006; Defran *et al*. 1990; Hillman *et al*. 2003; Karczmarski & Cockcroft 1998; Kreho *et al*. 1999).

Obtaining good quality images of dorsal fins is of paramount importance to obtaining an unbiased estimate of abundance using photo-ID CMR methods. During a survey, thousands of images may be taken, particularly with advent of digital cameras. Processing these photos in a consistent manner is a critical step. Current practice is to use only high quality photos of well-marked fins in the CMR models.

Two parameters are of utmost importance when using dorsal fin photos for photo-ID CMR abundance estimation: image quality and fin distinctiveness. A variety of systems for grading these two parameters have been developed (Baird *et al*. 2009; Durban *et al*. 2010; Ottensmeyer & Whitehead 2003; Slooten *et al*. 1992; Urian *et al*. 1999; Wilson *et al*. 1999). The method of Urian et al. (1999) has been most commonly used in recent publications of photo-ID based abundance estimates for bottlenose dolphins along the East Coast and Gulf of Mexico. Their grading scale for image quality is based on 5 image characteristics (Box 3): 1) image focus/clarity; 2) degree of contrast between the fin and background; 3) the angle of the fin to the plane of the photograph; 4) the amount of the dorsal fin visible; 5) the proportion of the frame that is filled by the fin.

Box 3. Measuring Image Quality*	
Focus/Clarity	Excellent, Moderate, Poor (very blurry)
Contrast	Ideal, Excessive or Minimal
Angle	Perpendicular, Slight Angle, Oblique
Proportion of fin visible in photo	Fin Fully Visible (leading & trailing edge), Fin Obscured
Proportion of frame filled by the fin	> 5%, < 1%
*from Urian et al. 1999	

Using a cumulative score across all 5 categories, each image receives a final image quality score: Q-1 (excellent quality), Q-2 (average quality), or Q-3 (poor quality). It is important to note that scoring of image quality must be conducted independently of scoring the distinctiveness of the fin in the photo.

Scoring fin distinctiveness is an equally important component of photo analysis for CMR. Under the Urian et al. (1999) system, overall fin distinctiveness is graded as: D-1 (very distinctive), D-2 (average distinctiveness) or D-3 (not distinctive). A D-1 fin is a distinctive fin that is identifiable in both a poor quality photo or when the fin is distant from the camera. A D-2 fin is a fin that is characterized by one major distinctive feature or two obvious features (nicks, notches etc.). D-3 fins either have no distinctive features or have features so subtle that they would only be identifiable in a photo of the best quality possible or would require the analyst to zoom in on the fin to distinguish the individuals from others possessing similar fin features.

Image quality and fin distinctiveness interact to provide those fin images that are appropriate for a CMR analysis. All photos, regardless of the uniqueness of the fin must be treated equally. It is inappropriate, for example, to include poor quality photos of an identifiable distinctive fin in a

CMR analysis when an image of an unmarked fin possessing a similar image quality score would be excluded. Then, only high quality photographs of D-1 and D-2 fins are used in a CMR analysis

Best Practices

Upon reviewing the ecology of BSE bottlenose dolphin stocks and aspects of photo-ID surveys, photo analysis and CMR analyses, workshop participants sought to generate a list of best practices for each step in the process of a photo-ID CMR study. These practices attempt to provide guidance applicable to the varied types of habitats and ecologies seen across BSE stocks. During this process, a list of future needs and directions was also compiled (See Future Work).

Based on the stated goal of estimating abundance of resident dolphins, with residents defined as dolphins that spend greater than 50% of their time within a delimited stock region, Workshop participants agreed upon the following best practices:

Survey design

Survey design is critical and must ensure adequate data, avoid dilution of effort, meet critical assumptions of population closure and adequate mixing of marked and unmarked individuals and address longer-term issues of temporary emigration/immigration.

Survey design must be robust to violations of assumptions of a proposed analysis approach. Workshop participants recommended the Robust Design as the most appropriate approach, particularly when the presence of non-residents is an important aspect of the dynamics of the system.

In the Robust Design, the primary period is typically at the seasonal scale. At least four primary periods (seasonal) are recommended and should be sufficiently spaced temporally to reduce the likelihood that non-resident animals will be seen during consecutive primary periods. For example, if non-residents are present for one month, primary periods should be separated by two months. The optimal number and timing of primary sessions are likely to be situation dependent. When longer-term field studies are possible, residents can be identified based on association patterns thereby allowing removal of non-residents from the analysis. However, even this method cannot account for non-residents with non-distinctive fins.

Within primary periods, three or more secondary sessions should be conducted. A secondary session is defined as a complete survey of the entire study area. Sessions should be designed so that one can reasonably expect to see 50% of the population during each primary period. During each secondary session, this would require a capture probability ranging from 0.2-0.3.

For secondary sessions, there should be sufficient opportunity for mixing of animals between each session. This requirement may be accomplished by temporally spacing the sampling of particular areas by one or more days, but time between sessions should not be so long as to risk violating the assumption of population closure (i.e., short enough that the probability of a non-resident entering or leaving the population is low). The appropriate length of separation between sessions will be dependent upon the behavior of animals within the estuary.

Survey effort should be designed to minimize heterogeneity in capture probabilities due to geographic factors, sighting conditions, animal behavior, etc., as CMR estimates of abundance are very sensitive to this heterogeneity. Steps that can be taken include randomizing the starting and ending points of each session to avoid time bias (e.g., repeatedly capturing animals that exhibit site fidelity to a particular area and time of day, experiencing glare in the same area each survey etc.), altering the time of day a specific area is surveyed in different passes, surveying only in low sea states, randomizing crews over different parts of the study area, randomizing crew positions on the boat, and following other best practices. Covariates thought to influence capture probabilities should be recorded, and where possible, used as explanatory variables within mark-recapture analyses.

Survey effort should attempt to maximize capture probabilities, as this will provide more accurate abundance estimates and allow modeling of required parameters. Survey trackline orientation and number of tracklines should be structured such that sufficiently high capture probabilities are reached and the potential for capture heterogeneity is minimized.

The geographic scope of the survey should systematically sample the entire stock range unless mixing is known to be complete. If mixing is homogeneous, then information on animal distribution (e.g., the observation of "hot spots" or areas not often used by dolphins) can be used to modify the survey design to increase effort in areas of high animal occurrence, and decrease (but not eliminate) effort in lower density areas. To ensure that a random, representative sample of the population is obtained, survey efforts should not be focused exclusively in areas of high animal occurrence. When entering new estuaries where little or no previous field work has been conducted, it is difficult to know how to design survey routes that will adequately minimize capture heterogeneity, maximize capture probabilities and ensure mixing between sessions. In these cases, it may be best to start with broad geographic coverage using uniform survey blocks until the degree of mixing and preferred dolphin habitat areas are revealed. Tracklines can then be stratified as more information is obtained. Ancillary data sources, such as satellite or other telemetry data, can be helpful in the determining the initial geographic extent to be surveyed for a CMR study.

For estimation of resident abundance, surveys should be conducted during periods in which adjacent stocks are least likely to overlap. For example, if you know that non-resident pulses occur in a certain season or time frame, do not plan surveys for that period. Care should be taken not to design surveys in such a way that individuals would be likely to be counted in abundance estimates for more than one stock.

Field work

Boat crews are minimally comprised of three people – a driver and left and right observers.

Surveys should be conducted under "standardized" viewing conditions – i.e., with good visibility and low sea states (Beaufort 3 or less).

Surveys should typically be conducted at speeds of 10-14 knots and no more than 20 kts. Speeds must allow sufficient opportunity to detect dolphins (Dawson *et al*. 2008). Dedicated observers <u>must actively search</u> for dolphins, allowing the boat driver to focus on safe operation of the vessel. To test whether your survey speed is too fast, slow down occasionally and search for dolphins. If you consistently sight dolphins after slowing, but not at survey speed, your survey speed is likely too high.

Upon encountering a group of dolphins, the ultimate goal is to parallel the dolphins and match their speed so that perpendicular photos of dorsal fins may be taken. The following are to be AVOIDED:

- Driving too fast around dolphins
- Getting the boat ahead of the dolphins while attempting to get parallel
- Turning into the dolphins; always turn out and away from dolphins in order to maintain space between the dolphins and the boat
- Putting dolphins in glare
- Charging at dolphins; always approach slowly
- Sudden or too frequent shifting or throttle changes and boat movements. Avoid abrupt and repetitive changes in heading and speed when following dolphins
- Throttling down immediately upon seeing dolphins; better to continue past a short distance then slow, and turn back.
- Getting too close
- Crossing behind or in front of dolphins' position or path
- Driving to dolphins' previous surfacing location and idling; always try to anticipate where the dolphins will be in the next surfacing
- Splitting groups
- Grinding outboard gearbox; can cause dolphins to startle or become more skittish
- Prolonging sighting unnecessarily; take only the minimum amount of time needed to collect all relevant data
- Don't make this an unpleasant experience for the dolphins. Stay attentive and observant and be sensitive to their cues. Finish with a group before they are finished with you. If the dolphins become evasive, you have been with them for too long, and you will experience diminishing returns in terms of photo coverage.

Photographers should have experience working in close proximity to dolphins and collecting effective photographs for photo-ID purposes. Likewise, vessel operators should be skilled at operating the boat in a variety of environmental conditions and should be experienced in maneuvering around dolphins so as to keep harassment of the animals to an absolute minimum.

Photographers should strive to <u>photograph every dolphin in an encounter</u>, marked and unmarked. If the group is too large to meet that objective, then it is critical that a <u>random sample of the animals present</u>, marked and unmarked, be photographed. Spend equal effort photographing all animals. At the same time, it is important to adhere to a time limit when engaged with a group so as not to harass them for too long.

Careful consideration should be given to whether to include calves in a CMR analysis. Young animals that are still strongly tied to their mothers do not constitute an independent sample since they are unlikely to mix randomly with the population. Most young animals likely won't be used in the analysis because they will not be marked. A description of a CMR analysis should state whether marked calves were used or not and what impact that may have had on the abundance estimate.

Photos should be taken, however, because data on putative mother/calf relationships as determined from photos showing identifiable larger animals in association with calves can be important for measures of fecundity and calf survival.

A group of dolphins is defined as animals in close proximity to one another (100m or less) exhibiting similar behavior and moving in the same general direction. Operationally, this term can be used interchangeably with "sighting" or "encounter."

<u>GPS coordinates</u> should be recorded for each dolphin group encountered, at a minimum, at the beginning and end of the photo session. Recordings in decimal degrees are the most oft used measure

<u>Environmental covariates</u> including location (longitude and latitude in decimal degrees), sighting conditions, water column characteristics (depth, temperature, salinity), tides, time of day, photoperiod) should be recorded at each sighting location. This information should also be recorded at the beginning and end of the survey and any time during a survey when one changes dramatically. These data may be used to understand factors that influence dolphin distribution and capture probabilities within the study area.

Photo analysis and matching
Utilize accepted photo quality and fin distinctiveness scoring criteria (for example see Appendix II) to reduce potential problems associated with introducing false positive or false negatives, or missed matches or incorrect matches.

Image quality and fin distinctiveness should be graded separately by independent researchers in order to minimize the influence of the quality of the image on the scoring of fin distinctiveness and vice versa.

<u>Fin distinctiveness</u> is a critical component of CMR estimates. A fin must be able to be reliably matched with any photo of that fin that meets the image quality criteria. Do not use fins with subtle marks. Fins must have clearly visible, useful features, not ones that must be squinted at. Do not use distinctive animals in poor quality photos even though they are easy to identify. You would not use an unmarked fin in a poor quality photo. All aspects of processing distinctive and non-distinctive fins must he handled equivalently and held to the same standard. However, highly distinctive fins in photos of poor quality should be retained separately for other, non-CMR analyses such as determinations of social or ranging patterns.

To test the impact of fin distinctiveness scoring on the abundance estimate, researchers may consider comparing an abundance estimate obtained by using only D-1 fins to that obtained

using both D-1 and D-2 fins. Inclusion of less distinctive fins could bias an abundance estimate upwards as recapture rates would be lowered (see Read et al. 2003 for example).
Matching of fins should be carried out independently by two people. One person can perform the first round, but results should be verified by a second person. Each new photograph should be compared against the entire catalog. If a match is found, it should be independently verified by a second person. Any photo not matched to an existing catalog entry during this process should be compared against the catalog again by a second person and any subsequent matches by this second pass should also be independently verified. It would be useful to provide certainty values on each match as well.

A variety of metadata associated with each photo should be kept in a database. Along with the standard camera metadata (date, frame number, camera body, lens, exposure etc.), image quality and fin distinctiveness grading, and survey data (date, survey number, sighting number, trackline, waypoint, environmental covariates, etc.) should be included.

A step-by-step record or audit trail of how each photo is processed should be maintained. In addition, an audit trail of any changes to a fin's identification number should be kept.

Estimation of matching error rates through a blind experiment in which known photos are seeded into the matching process may be useful to identify potential sources of bias.

Archive all photos, or at a minimum all photos containing some portion of an animal or fin. While these images may not be appropriate for CMR analyses, they may be of use for other analyses. These images don't need to be included in a catalog, but should be archived and stored such that they could be accessed in the future.

CMR analysis

Appropriate modeling is needed to address sources of variation that cannot be dealt with through sampling design, to produce unbiased estimates of abundance, and to efficiently use complex datasets.

Use only high quality photos and distinctive fins in the CMR analysis.

Dealing with non-residents is an important aspect of obtaining an abundance estimate appropriate to the resident stock. Current analysis software does not provide a means to analyze data from the Robust Design to account for non-resident animals but such models are under development. Careful survey design must be incorporated if non-resident animals are suspected to be an issue.

If non-residents are not an important component of the dynamics within a region, then simple closed population designs can be applied if effort is sufficient to allow estimation of individual heterogeneity in capture probabilities.

The Program MARK is commonly used in CMR analysis. RMARK is a suggested alternative to using Program MARK through the R programming language, because it creates reproducible code that can be easily shared.
One goal of data analysis should be reproducibility of results. Records of data manipulation should be maintained so that results can be reproduced by another researcher. It is generally better to use existing code rather than writing your own code, but any new code should be reproducible and be made available to other researchers.

Abundance estimates must be corrected for the proportion of animals with unmarked fins. In order to accomplish this, a high quality photo should be obtained (1) of every fin, marked or unmarked, in an encounter or, when that is not possible, (2) from a random sampling of fins in the group. If a group is small enough, it is often possible to identify every individual and one can get exact counts of the number of marked and unmarked fins in the encounter (Durban *et al.* 2010). However when the number of dolphins in an encounter is large or they are spread out over a wide area, then it is necessary to estimate the number of unmarked fins in the encounter and then over the entire study as a whole. Workshop participants recommended that the proportion of unmarked fins (D-1+D-2)/(D-1+D-2+D-3) be estimated for each encounter. These values can then be examined to determine whether the proportion of identifiable individuals is roughly constant over encounters, in which case, these estimates can then averaged across encounters for the entire study period using either simple averages or a ratio estimator (total numerator/total denominator over all encounters). If the proportion of identifiable individuals is very heterogeneous, this variation must also be included in the estimation procedures.

As with other steps in the process, an audit trail of how and when the catalog was queried to determine the proportion of distinctive fins should be maintained so that someone else could reproduce what was done and obtain the same result.

Future work

Workshop discussions also generated a variety of suggestions for additional topics that should be addressed, future work for improving analytical tools, and ways to increase consistency across studies.

Photo-analysis

It was suggested that it would be useful to hold a workshop to address some lingering topics related to photo-analysis. In particular, it was agreed that there is room for standardizing the definition of fin distinctiveness. Potential workshop topics could include: Should there be distinctiveness criteria? If so what should they be (i.e., how many features are needed to define distinctiveness)? Can standards be developed for the size or the depth a mark must be in order to be considered a distinctive feature? Are there other distinctive features that could be useful (e.g., freezebrands, presence of *Xenobalanus*)? In addition, the workshop scope could include a blind experiment to survey how active researchers score fin distinctiveness and image quality, to inform the process of trying to identify distinctiveness criteria and to create consistency across studies. Finally, there was discussion that the workshop could also identify criteria for scoring success rates of individual researchers and provide general suggestions on ways to improve results. Workshop participants felt that if scoring criteria and practices could be standardized, consistency of abundance estimates across sites would be enhanced.

Participants also recognized that improved software for matching could be enhanced or developed to expedite image processing time and matching within and amongst dorsal fin catalogues. Incorporation of new developments in facial recognition software is one possible venue of exploration.

CMR analysis

Workshop participants encouraged the development of simulation tools that could be used to investigate trade-offs between the number of primary periods and the number of secondary sessions given the characteristics of bottlenose dolphin populations such as: number and length of stay of non-residents, temporary movement out the study area by resident animals, individual heterogeneity in capture probabilities, degree of mixing (interchange rates), etc.

Because current software can not adequately deal with non-residents in models for the robust design, workshop participants recommended the development of special purpose code for use in BSE photo-ID abundance estimation.

Workshop participants also recommended that software be developed that can incorporate the proportion of unmarked fins into the abundance estimation process to replace the current method of post hoc adjustment of the abundance estimate. Finally, software that addresses the issues of mark modification/evolution and false negative matches (i.e., failing to match a known animal) would also be helpful.

A potential concern for long-term studies is mark evolution. A rigorous examination of how dorsal fin marks evolve through time would be particularly useful. Violations of assumptions about tag evolution (tag loss and gain) will impact the accuracy of abundance estimates in ways that are not completely clear. A rigorous empirical examination could provide information needed to incorporate a model of tag evolution into the CMR analysis.

Other Recommendations

It was recommended that Permit application packages sent out to those requesting a General Authorization for Scientific Research under the MMPA in the Southeast U.S. should include the results from this Workshop and submitted proposals should be judged, in part, against their adherence to the best practices outlined by the Workshop. These recommendations could also be taken into account during peer review of manuscripts and provided to editors along with the reviews.

It was also recommended that a website be created to provide information on various aspects of photo-ID CMR analysis of bottlenose dolphins. Suggestions included: a) list the best practices outlined by the Workshop; b) maintain a repository of Program MARK or RMARK or special purpose code written to address some of the problems distinct to CMR efforts in bottlenose dolphins; c) provide examples of appropriate models to use for CMR analysis; d) provide examples of appropriate survey designs for different types of BSE habitats (large open waters, tidal creeks, etc.); e) present examples of recommended survey block designs depending on the amount of information known a priori about dolphin habitat usages within the study area (hotspots, areas known to harbor few animals, etc.); f) list examples of published papers with appropriately designed surveys and analyses.

Appendix I. Sizes of Gulf of Mexico bay, sound and estuary areas (compiled from Gulfbase.org).

ESTUARY	SURFACE AREA (KM^2)	~LONGEST DIMENSIONS (KM)
Laguna Madre	3658	176 X 15
Nueces Bay, Corpus Christi Bay	497	23 x 17
Copano Bay, Aransas Bay, San Antonio Bay, Redfish Bay, Espiritu Santo Bay, Matagorda Bay, Tres Palacios Bay, Lavaca Bay	2163	148 x 20
West Bay	101	44 x 8
Galveston Bay, East Bay, Trinity Bay	1298	40 x 40
Sabine Lake	243	28 X 14
Calcasieu Lake	256	28 X 19
Vermillion Bay, West Cote Blanche Bay, Atchafalaya Bay	1821	90 X 27
Terrebone Bay, Timbalier Bay	1761	98 X 32
Barataria Bay	1673	21 X 35
Mississippi River Delta	1554	100 X 70
Chandeleur Sound, Breton Sound	5403	88 x 51
Bay Boudreau, Mississippi Sound	4792	131 X 22
Mobile Bay, Bonsecour Bay	1059	50 X 35
Perdido Bay	130	21 X 8
Pensacola Bay, East Bay	370	34 X 20
Choctawhatchee Bay	334	40 X 9
St. Andrew Bay	243	65 X 6
St. Joseph Bay	178	21 X 10
St. Vincent Sound, Apalachicola Bay, St. Georges Sound	554	73 X 10
Apalachee Bay	412	74 x 29
Waccasassa Bay, Withlacoochee Bay, Crystal Bay	n/a	65 x 20
St. Joseph Sound, Clearwater Harbor	113	28 x 5
Tampa Bay	896	49 x 36
Sarasota Bay	114	18 x 5
Little Sarasota Bay	8	11 x 2
Lemon Bay	21	17 x 1
Pine Sound, Charlotte Harbor, Gasparilla Sound	805	48 x 23
Caloosahatchee River	n/a	28 x 2
Estero Bay	759	27 x 5
Chokoloskee Bay, Ten Thousand Islands, Gullivan Bay	n/a	60 x 16
Whitewater Bay	n/a	25 x 10
Florida Keys (Bahia Honda to Key West)	n/a	75 x 34

Appendix II. Measurement of Photographic Quality and Dolphin Distinctiveness for the Mid-Atlantic Bottlenose Dolphin Photo-ID Catalog. Kim Urian, Curator

OVERALL PHOTOGRAPHIC QUALITY

Overall Photographic Quality is based on the quality of the photograph **independent** of the distinctiveness of the fin.

The Overall Photographic Quality score is based on an evaluation and sum of the following characteristics (these scores are absolute values, not a sliding scale):

Focus/Clarity

Crispness or sharpness of the image. Lack of clarity may be caused by poor focus, excessive enlargement, poor developing or motion blur; for digital images, poor resolution resulting in large pixels.

Based on the scale:

2 = excellent focus 4 = moderate focus 9 = poor focus, very blurry

Contrast

Range of tones in the image. Images may display too much contrast or too little. Photographs with too much contrast lose detail as small features wash out to white. Images with too little contrast lose the fin into the background and features lack definition.

Based on the scale:

1 = ideal contrast 3= either excessive contrast or minimal contrast

Angle

Angle of the fin to the camera.

Based on the scale:

1 = perpendicular to camera 2 = slight angle 8 = oblique angle

Partial

A partial rating is given if so little of the fin is visible that the likelihood of re-identifying the dolphin is compromised on that basis alone. Fins obscured by waves, *Xenobalanus*, or other dolphins, would be evaluated using this rating.

Based on the scale:

1 = the fin is fully visible, leading & trailing edge 8= the fin is partially obscured

Proportion of the frame filled by the fin

An estimate of the percentage area the fin occupies relative to the total area of the frame.

Based on the scale:

1 = greater than 5%; subtle features are visible 5 = less than 1%; fin is very distant

To score Overall Photographic Quality, sum the scores for each characteristic:

6 - 9: Excellent quality **=> Q-1**
10–12: Average quality **=> Q-2**
>12: Poor quality **=> Q-3**

OVERALL DISTINCTIVENESS

Overall Distinctiveness is based on the amount of information contained on the fin; information content is drawn from leading and trailing edge features, and pattern, marks, and scars.

D-1 - Very distinctive; features evident even in distant or poor quality photograph

D-2 - Average amount of information content: 2 features or 1 major feature are visible on the fin

D-3 - Not distinctive; very little information content in pattern, markings or leading and trailing edge features

These measurements are derived from:
Friday et al. 2000. Measurement of photographic quality and individual distinctiveness for the photographic identification of humpback whales, *Megaptera novaeangliae*. Marine Mammal Science 16: 355-374

For some study areas, it may be useful to score the presence of the barnacle *Xenobalanus,* which often attaches to dorsal fins. The following scoring system was provided by T. Eguchi (pers. comm. NOAA Fisheries, SWFSC)

This category is solely based on how much *Xenobalanus* exists on the leading and trailing edges of the dorsal fin. Those barnacles that attach to the surface of the fin are not considered in this rating, because they do not affect the identification of the fin. There are five ratings in this category:

A - No *Xenobalanus* exists on the trailing edges of the fin.
B - Up to 25% of the trailing edge is obscured by *Xenobalanus*.
C - More than 25% but less than 50% of the trailing edge is obscured by *Xenobalanus*.
D - More than 50% but less than 75% of the trailing edge is obscured by *Xenobalanus*.
E - More than 75% of the trailing edge is obscured by *Xenobalanus*.

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Workshop Agenda
Workshop on Estimating Abundance for Estuarine Populations of Bottlenose Dolphins

January 19-21, 2010 Atlanta, GA

"Not everything that can be counted counts, and not everything that counts can be counted..."
- Albert Einstein (attributed)

Wednesday, January 19, 2011

8:30-9:00 Introduction (P. Rosel, K. Mullin, L. Garrison, NOAA Fisheries)

- Welcome, housekeeping
- Introductions
- Appointment of rapporteurs
- Agenda review and schedule

Morning Session: Framing of the workshop and background on issues relevant to abundance estimation for estuarine populations of bottlenose dolphins

9:00-9:30 Overview of bay, sound and estuary (BSE) stocks and needs for abundance estimation in the Atlantic and Gulf of Mexico, difficulties encountered (P. Rosel, NOAA Fisheries)

9:30-10:30 Overview and general considerations for mark-recapture (MRC) abundance estimates (M. Conroy, Univ. Georgia)

10:30-10:45 Break

10:45-11:45 Mark-recapture abundance estimates for BSE stocks- in practice. (B. Balmer, Univ. North Carolina Wilmington; E. Zolman, NOAA NOS)

12:00-1:00 Lunch

Afternoon Session: Definitions of Residents vs. Transients

1:00-2:00 What is known about the patterns of residency in BSE populations? (R. Wells, CZS)

2:00-2:30 How do different assumptions of residency impact abundance estimates? (P. Conn, NOAA Fisheries)

2:30-2:45 Break

2:45- 3:45 Discussion: How should residency be defined? (L. Garrison)

3:45-5:00 Discussion: What methods are available or additional data are required to separate resident from non-resident animals in abundance estimates? How best account for uncertainty in who was counted during the survey? (L. Garrison)

Thursday, January 20, 2011

8:00-8:30 Recap of Wednesday's sessions and any follow-up

Morning Session: Photo-ID MRC Analytical Considerations

8:30-9:00 Overview of the analytical options, etc. for estimating abundance of Bay, Sound and Estuary populations using photo-ID MRC methods (C. Schwarz, Simon Fraser University).

9:00-10:30 Discussion: What analytical approaches are needed for Bay, Sound and Estuary populations considering habitat types, seasonal changes in usage, habitat variability , potential for overlapping stocks, etc. (T. Eguchi)

10:30-10:45 Break

10:45-12:00 Discussion: What standards and/or best practices for data analysis should be followed by all researchers with the goal of creating written guidelines. (T. Eguchi)

12:00-1:00 Lunch

Afternoon Session: Photo-ID MRC Survey Design Considerations

1:00-1:30 Overview of the issues, options, etc. in survey design for estimating abundance of Bay, Sound and Estuary populations using photo-ID MRC methods (L. Garrison, NOAA Fisheries).

1:30-3:00 Discussion: What design constraints are needed for Bay, Sound and Estuary populations? Focused discussion to tailor approaches based on habitat types (e.g., large area of open water with many passes to ocean/gulf waters, small area of open water with one or two passes, and rivers and tidal creeks) and degree of information already available for a site. (E. Zolman)

3:00-3:15 Break

3:15-5:00 Discussion: What standards and/or best practices for survey design and field work should be followed by all researchers with the goal of creating written guidelines. (E. Zolman)

Friday, January 21, 2011

8:30-9:00 Recap of Thursday's session and any follow-up

Morning Session: Photo-Analysis

9:00-9:30 Review of current methods used for photo-analysis (quality scoring, matching, verifying etc.). (K. Urian, Duke University)

9:30-10:30 Discussion: What standards and/or best practices should be followed by all researchers? (L. Schwacke)

10:30-10:45 Break

10:45-12:00 Discussion: Long-term photo-ID catalogs- impetus, goals and function. (L. Schwacke)

12:00-12:30 Summary, Synthesis, Wrap-up (Where should we go from here?)

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