Aerial Surveys of Manatees: A Summary and Progress Report

by

Bruce B. Ackerman

Florida Department of Environmental Protection
Florida Marine Research Institute
100 Eighth Avenue S.E.
St. Petersburg, Florida 33701

Abstract. Aerial surveys are used to document the distribution and relative abundance of Florida manatees (*Trichechus manatus latirostris*) and to assess population trends. Recent research included aerial surveys by various agencies to determine the distributions of manatees in 10 areas of Florida. In most of these studies, twice-monthly flights were made for at least 2 years. Surveys of distributions have now been made in all areas of the state that are extensively used by manatees. The resulting data have been used for the protection of manatees. Various groups conducted counts of manatees at aggregation sites in winter at selected power plants and at the Crystal River and Blue Spring. These counts have been used to assess population-size trends. Based on mandates by the state legislature, a 2-day, synoptic aerial survey was made to obtain a single annual high count by maximizing survey effort under optimal conditions. These surveys followed two major cold fronts each winter in 1991 and 1992. On 17–18 January 1992, a high count of 1,856 manatees was made (907 on the eastern coast, 949 on the western coast, 8.7% calves). Although not statistical estimates, these counts provide new information about the minimum size of the population. The higher synoptic-survey counts are not proof of an increase of the population through time but are consistent with increases in long-term counts in some areas of the state, including aerial counts at the Crystal River, ground counts at Blue Spring, and counts of aggregations at power plants adjusted for temperature covariates. Current research on aerial surveys is focused on new techniques to improve estimates of population size and trend.

Key words: Aerial surveys, Florida manatee, synoptic survey, trends, *Trichechus manatus latirostris*, warm-water refuges.

Aerial surveys to count and map the distribution of Florida manatees (*Trichechus manatus latirostris*) have been used since 1967 (Hartman 1979). Various methods to survey manatees were used by subsequent researchers (*[1]Hartman 1974; Irvine and Campbell 1978; *Rose and McCutcheon 1980; Irvine 1982; Irvine et al. 1982; Shane 1983; Kinnaird 1985; *Packard 1985; Reynolds and Wilcox 1985, 1986, 1994; Packard et al. 1986). Aerial surveys are useful and cost-effective for counting manatees and for mapping manatee distribution and seem to be the only method with which large numbers of manatees in large areas can be counted. Distribution data have been used extensively for the protection and management of manatees. However, aerial surveys have significant drawbacks for obtaining precise population-size estimates (*Eberhardt 1982; Packard et al. *1984, 1985; Lefebvre et al. 1995). Manatees are difficult to detect and, once seen, are often difficult to count accurately (Packard et al. 1985, 1986). Therefore, aerial counts are generally assumed to be too low. Lefebvre et al. (1995) discussed the theory and the problems of aerial surveys of manatees, particularly for the estimation of population sizes and trends.

My objectives were to provide descriptions of recent and ongoing aerial surveys of manatee distribution, surveys of manatee aggregations in winter, and synoptic surveys. Descriptions of each of these survey categories include statements of survey objectives, summaries of employed procedures, results, and inherent problems and limitations. I also provided information on population size and trend based on

[1] An asterisk denotes unpublished material.

aerial surveys and gave brief descriptions of new research to improve survey techniques.

This paper is largely a summary of all recent information on aerial surveys of manatees and interpretation of results of these surveys, particularly as they relate to estimation of manatee distribution, population size, and trend. Considerable resources are expended on this topic by several organizations, but many of the results appear in technical documents, agency files, or other unpublished sources. I examined these sources and tabulated descriptions to provide a comprehensive overview of aerial survey activities, focusing on work carried out since 1986. Studies prior to 1986 were previously reviewed by Packard (*1985), Beeler and O'Shea (*1988), and O'Shea (1988).

Reviews of methodology employed in previous studies are included under the heading of procedures in descriptions of surveys of manatee distribution and surveys of manatee aggregations in winter. I present original information, including the first published description of the objectives, procedures, and results of synoptic surveys. I also analyzed data on trends in counts of manatees in the Crystal River and at Blue Spring with regression techniques. Details on methods for obtaining and analyzing original information are provided in the sections devoted to these topics.

Recent and Ongoing Aerial Surveys

Surveys of Distribution

Objectives

The purpose of surveys of distribution (extended-area surveys, *Packard 1985) is to document the spatial distribution and seasonal habitat use of manatees. Although these surveys do not give accurate population-size estimates, they provide a minimum estimate of the number of animals in an area on a given day. Abundance is usually considered to be relative because it is believed (or hoped) to include a roughly constant proportion of the animals. Surveys over a large area are made repeatedly during 1 or more years and provide data on seasonal and yearly changes of relative abundance. Data from these surveys have been useful for management because they reveal areas of high seasonal usage and support the protection of manatees (e.g., restrictions on boat speeds or conditions for development).

Procedures

The following is a summary of procedures by the Florida Department of Environmental Protection; the procedures are similar to those of other agencies. The procedures typically followed protocols established by earlier studies such as those by Shane (1983), Kinnaird (1985), Provancha and Provancha (1988), and Rathbun et al. (1990). Some studies may vary from these guidelines, but for each study, procedures are kept as consistent as possible to maximize comparability of counts.

Most aerial surveys are conducted with a Cessna 172 or with a similar small, high-winged, 4-seat airplane with good downward visibility (Irvine 1982). Small helicopters have also been used but are more expensive (Rathbun 1988). Helicopters are useful for surveys in urban or residential areas and in congested airspaces such as near major airports. Pilots experienced in low-altitude, slow-speed, circling flight are used. One or two experienced observers are usually seated on the right side of the aircraft; the door is attached and the window is open. Observers wear polarized sunglasses to reduce glare. The primary (most experienced) observer has a minimum of 30 hours experience in aerial surveys of manatees, has detailed knowledge of the survey area, and sits in the right front seat. A secondary observer is not required for most survey areas but, if used, usually sits in the right rear seat. However, if wide expanses of shallow water are covered, the second observer can view from the left rear seat to help cover the area more effectively (Irvine 1982; Shane 1983; *Packard et al. 1984). A higher proportion of manatees is seen with two experienced observers than with one.

Flights are usually at an altitude of 150 m and at an air speed of 130 km/h. When manatees are seen, the airplane slows and circles the area clockwise until the observer is reasonably sure that an accurate count was made (i.e., until repetitive counts become consistent). Manatees may be spotted by any observer or by the pilot, but manatees are officially counted and mapped only when confirmed by the primary observer (*Packard et al. 1984). Counts are more consistent when the same observers are used each time.

Surveys follow a standardized flight path and are designed to cover the most probable manatee habitats in an area, as described by Irvine (1982), Shane (1983), Packard (*1985), and Rathbun et al. (1990). The route is marked in advance on National Oceanic and Atmospheric Administration 1:40,000 navigation charts or U.S. Geological Survey 1:24,000 topographic maps, and observations are written on the maps. Since 1992, the Florida Department of Environmental Protection has used a portable global positioning system unit (Trimble Pathfinder Basic Plus, Trimble Navigation, Sunnyvale, California) to accurately store information on the position of sightings and the flight path. Routes may include coastal areas, major rivers and estuaries (usually to depths of 3 m) and their tributaries, and freshwater and saltwater canals. Surveys are intensified over aggregation sites in winter, areas within 500 m of shore, offshore areas (shoals) that are shallower than

2 m, areas with aquatic vegetation, freshwater sources, and areas in which manatees have been sighted historically.

High-density concentrations of manatees such as those at power plants are surveyed intensively (intensive-area method; *Packard 1985). Each small area is circled clockwise at least twice before the aircraft moves on. This technique takes more time but gives a higher probability of detecting manatees, including manatees that rest on the bottom and must rise for a breath while the aircraft is passing over. Surveys in areas of low manatee density are less intensive (extended-area method; *Packard 1985). Only one pass is made over each area, which reduces the probability of seeing all manatees but allows sampling in a larger area.

Wide expanses of shallow water (e.g., Indian River, Whitewater Bay) have been covered in a series of transects that were 0.8 km apart (Odell 1979; Shane 1983). Wide expanses of deeper water, such as Tampa Bay, are only covered along the shoreline and around spoil islands (*Reynolds et al. 1991). This allows coverage of a larger area in a given amount of time but decreases the probability of detecting all the manatees.

Recent Florida Department of Environmental Protection surveys were typically conducted twice per month for 2 or more years. The unpublished protocols are similar to those of other agencies (Shane 1983; Provancha and Provancha 1988; Rathbun et al. 1990). Data about each survey flight are recorded on standardized forms and include date; start and end time; observer and pilot names; and aircraft type, speed, and altitude. Weather and water conditions recorded for each segment of the flight include wind speed and direction, air temperature, percentage of clouds, water clarity (depth to which a manatee can be seen), and water-surface conditions. A scale of water-surface conditions was adapted from the Beaufort Scale (Woolf 1977:98): (0) smooth like glass; (1) ripples with appearance of scales, no foam crests; (2) small wavelets, crests of glossy appearance, not breaking, no whitecaps; and (3) large wavelets, crests beginning to break, scattered whitecaps. Flights are canceled at conditions rated 3 or higher. The best visibility below the water surface occurs in smooth, clear water in the presence of few clouds and a bright sun. Flying conditions are best in the presence of little wind and no fog or precipitation.

Data about each observed group are recorded on maps and include the number of adult and calf manatees and their locations and behavior. Calves are defined as animals closely associated with an adult but less than about half the adult's length (Irvine and Campbell 1978; Irvine 1982). Behavior categories include resting (motionless manatees), traveling (swimming manatees), feeding (recognized by the presence of a manatee in a vegetated area and a nearby plume of suspended sediment), and cavorting (group of manatees rolling, splashing, or swimming in tight circles). Most manatees are seen close to the flight path but not directly under the aircraft. Splashes, surface wakes, mud trails, and mud plumes may draw the observer's attention to more distant manatees (Irvine 1982). Manatees in aggregations or in clear water are easiest to find. In winter, aggregations occur at or near warm-water refuges and are often accompanied by large amounts of stirred-up mud. Photographs can confirm counts of groups in clear water but are not of much value for large groups in turbid water.

Results

More than 30 studies were made between 1984 and 1993 (Table 1). Studies through 1986 were reviewed by Beeler and O'Shea (*1988). Surveys have been conducted in most areas of the state since that time. In most studies, twice-monthly surveys were conducted year-round for 2 or more years. Results of many studies have not yet been published (see Table 1 for unpublished sources). Examples of long-term or extensive studies follow.

On the western coast of Florida, the U.S. Fish and Wildlife Service conducted surveys in Lee County during 1984–85 (R. K. Frohlich, Florida Department of Environmental Protection, unpublished data). Subsequent surveys by the department were of manatees in Charlotte, Lee, and Collier counties (Florida Department of Environmental Protection, unpublished data). The Mote Marine Laboratory conducted surveys in Manatee, Sarasota, and Charlotte counties from 1985 to the present (*Kadel and Patton 1992). Eckerd College and the department conducted surveys in Tampa Bay from 1987 to 1994 (*Reynolds et al. 1991; Eckerd College and Florida Department of Environmental Protection, unpublished data). A series of studies of distribution were conducted in northwestern Florida beginning in 1967, covering aggregation sites in winter and warm-season habitats (Charlotte, Dixie, and Levy counties; Powell and Rathbun 1984; Kochman et al. 1985; Rathbun et al. 1990; Chassahowitzka National Wildlife Refuge, unpublished data).

On the eastern coast of Florida, four teams from different agencies conducted simultaneous counts twice-monthly for 1 year during 1986 in five adjacent counties from Volusia to Martin counties (B. L. Weigle, Florida Department of Environmental Protection, St. Petersburg, Florida, and R. K. Bonde, National Biological Service, Gainesville, Florida, unpublished data). These coordinated surveys provided information about seasonal migrations of manatees. Provancha and Provancha (1988, *1989) conducted surveys of manatees in the Banana River from 1984 to the present, expanding the database provided by surveys conducted during 1978–80 by Shane (1983). These surveys revealed high use by manatees of the Banana River, especially during spring migration.

Table 1. Recent aerial surveys of distribution of the Florida manatee (*Trichechus manatus latirostris*).

Area	Dates	Citations
Eastern coast		
Southeastern Georgia (Camden County, Cumberland Sound, warm seasons)	May 1988–Aug 1989	Zoodsma (1991)
Southeastern Georgia (Camden, Glynn, McIntosh counties)	Jun 1989–May 1990	*[a]Valade (1990)
Nassau County	Oct 1986–Oct 1988	Zoodsma (1991)
Duval County	May 1988–Apr 1990	City of Jacksonville, Florida, unpublished report
Duval, Clay, St. Johns counties (lower St. Johns River)	Jul 1982–Jun 1983	Kinnaird (1985)
Duval County (lower St. Johns River)	May 1993–May 1994	Florida Department of Environmental Protection, unpublished data
St. Johns, Clay, Putnam counties (middle St. Johns River)	Jun 1985–Jun 1986	*CH_2M Hill (1986)
Nassau, Duval, St. Johns, Flagler, Volusia counties (ICW, coast)	Jul 1982–Jun 1983	Kinnaird (1985)
St. Johns, Flagler, Volusia counties (ICW, coast)	Mar 1991–Nov 1993	Florida Department of Environmental Protection, unpublished data
Volusia County (Tomoka River)	May 1985–Dec 1985	Florida Department of Environmental Protection, unpublished data
Brevard County	Jan 1978–Feb 1980	U.S. Fish and Wildlife Service, Shane (1983)
Brevard County (Banana River, warm seasons)	Jun 1984–Apr 1986; Feb 1987–ongoing	Provancha and Provancha (1988, *1989); National Aeronautic and Space Administration, unpublished data
Interagency cooperative aerial survey		
Volusia County (Halifax River, Tomoka River, Mosquito Lagoon) Brevard County (northern Indian River, Banana River, Banana Creek)	Dec 1985–Jan 1987	U.S. Fish and Wildlife Service, unpublished data
Brevard County (southern Indian River)	Jan 1986–Jan 1987	Brevard County, unpublished data
Indian River, St. Lucie counties	Jun 1985–Dec 1987	Florida Department of Environmental Protection, unpublished data
St. Lucie, Martin counties	Jan 1986–Jan 1987	U.S. Fish and Wildlife Service, unpublished data
St. Lucie, Martin counties	Aug 1990–Jun 1993	Florida Department of Environmental Protection, unpublished data
Palm Beach County	Aug 1990–Jun 1993	Palm Beach County, unpublished data
Broward, northern Dade counties	Jan 1988–Mar 1990	Florida Department of Environmental Protection, unpublished data
Broward County	Nov 1991–Jun 1993	Broward County, unpublished data
Dade County (Biscayne Bay)	Jul 1974–Jun 1975	*Odell (1976)
Dade County (County-wide)	Jun 1989–ongoing	Dade County, unpublished data
Western coast		
Citrus, Levy, Dixie counties Winter (Crystal River, Homosassa River) Summer (coast and rivers)	1967–ongoing	Hartman (1979); *Powell (1981); Powell and Rathbun (1984); Kochman et al. (1985); Rathbun et al. (1990); Chassahowitzka National Wildlife Refuge, unpublished data
Northern Manatee County	Apr 1985–Dec 1986	Florida Department of Environmental Protection, unpublished data
Pinellas, Hillsborough, northern Manatee counties	Nov 1987–May 1994	Reynolds et al. (1991); Florida Department of Environmental Protection and Eckerd College, unpublished data
Southern Manatee, Sarasota, northern Charlotte counties	Jan 1985–ongoing	Kadel and Patton (1992)

Table 1. *Continued.*

Area	Dates	Citations
Charlotte County	Jan 1987–Dec 1988	Florida Department of Environmental Protection, unpublished report
Lee County		
Core area	Jan 1984–Dec 1985	Florida Department of Environmental Protection, unpublished report
Hendry Creek	May 1988–Dec 1988	
Imperial River	Mar 1987–Feb 1988	
Deep Lagoon	Jul 1986–Feb 1988	
Collier County		
North Collier	Feb 1987–Feb 1988	Florida Department of Environmental Protection, unpublished report
Naples area	Jan 1986–Jan 1987	
Wiggins Pass area	Feb 1987–Sep 1987	
Marco Island area	Jan 1989–Dec 1990	
Everglades City	Jan 1986–Jan 1987	
Ochopee	Mar 1987–Feb 1988	
Port of the Islands	Jan 1986–Dec 1990	
Ten Thousand Islands (includes Everglades City, Ochopee, Port of the Islands)	Jan 1991–Nov 1993	
Everglades National Park	Sep 1973–Jun 1976	Odell (1979)
Everglades National Park	Dec 1979–Sep 1981	Everglades National Park, unpublished report
Everglades National Park	Mar 1990–Mar 1993	*Snow (1992)

[a] An asterisk denotes unpublished material.

In 1992, 10 surveys of distribution were in progress (3 by the Florida Department of Environmental Protection, 3 by other agencies, and 4 jointly by the department and other agencies; Table 1). The department conducted surveys in 1992 in St. Johns, Flagler, and Volusia counties (unpublished data); St. Lucie and Martin counties (unpublished data); Tampa Bay (*Reynolds et al. 1991; Florida Department of Environmental Protection and Eckerd College, unpublished data); and the Ten Thousand Islands in Collier County (unpublished data). Surveys were conducted in 1992 by the Broward County Office of Planning (D. Burgess, unpublished data), Palm Beach County Department of Environmental Resources (D. Carson, unpublished data), and the Everglades National Park (*Snow 1992), each co-sponsored by the Florida Department of Environmental Protection. Surveys were also conducted in Dade County by the Dade County Department of Environmental Resources Management (S. Markley, unpublished data), in the Crystal River area by the Chassahowitzka National Wildlife Refuge (J. Kleen, unpublished data), and in the Banana River by the National Aeronautic and Space Administration (Provancha and Provancha 1988, *1989, unpublished data).

These surveys provided a detailed, up-to-date coverage of all counties in the typical range of manatees. An extensive database of counts and distribution maps now exists for most of the state (Table 1; Fig. 1). These data were needed to support intensive manatee protection proposed in 1989 to regulate watercraft speeds in 13 counties in Florida (*Florida Department of Natural Resources 1989). Sighting data from all surveys conducted by the Florida Department of Environmental Protection and numerous other groups were digitized and entered into the department's Marine Resources Geographic Information System (O'Shea and Kochman 1990; Weigle and Haddad 1990). Maps were created that display manatee sightings from aerial surveys and locations where dead manatees were reported, locations of manatees tracked by telemetry, shorelines, aquatic habitats, shoreline development, boat ramps, sources of fresh and warm water, and water depths. The Marine Resources Geographic Information System has been used extensively by the department to develop protection of manatees in concentration areas and to plan watercraft and shoreline developments (Weigle and Haddad 1990; B. Ackerman and K. Clifton, in preparation).

Problems and Limitations

Surveys provide valuable data on the seasonal distribution and abundance of manatees and have now been conducted in all major areas in the typical range of Florida manatees around the state. They also provide detailed information on habitat use and have been used extensively to define areas that require legal protection. However, a major criticism of surveys of distribution is that they usually do not provide accurate or statistical

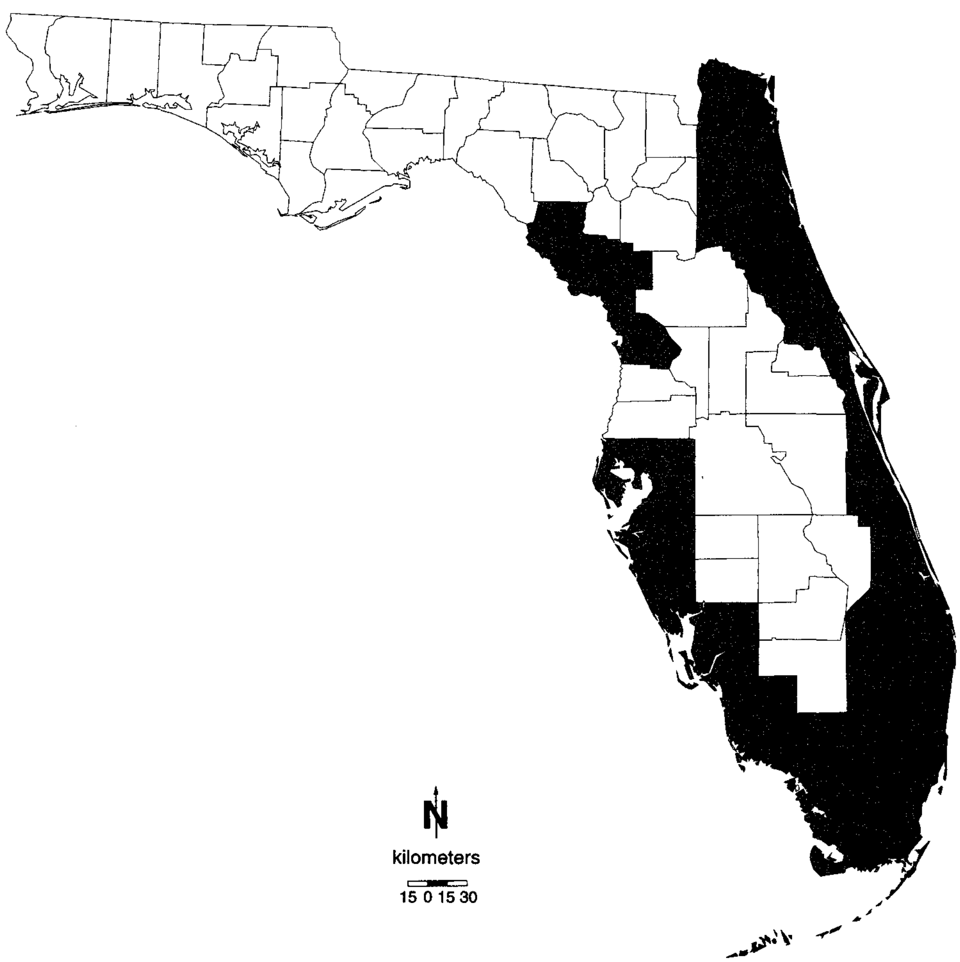

Fig. 1. Counties (*shaded*) in Florida where aerial surveys of manatee (*Trichechus manatus latirostris*) distribution were conducted.

estimates of the number of manatees present (*Eberhardt 1982; *Packard 1985; Lefebvre et al. 1995). Effort varies by flight and by area. Visibility biases are probably not equal among various habitats. Therefore, surveys of distribution do not provide good population-size estimates, especially where visibility bias is large.

Surveys by the Florida Department of Environmental Protection and others were usually conducted twice monthly for 2 years. This provided a sample of the manatees' seasonal distribution; however, a determination of whether this is a sufficient sample has not been possible. Twice-monthly surveys for 2 years seem more adequate than a smaller sample (less frequent or shorter duration surveys) for documenting manatee distribution. This schedule at least compensates for short-term weather changes between months and between consecutive years. But longer-term studies are needed to monitor changes in numbers or shifts in habitat use (Provancha and Provancha 1988, *1989; Rathbun et al. 1990; *Reynolds et al. 1991; *Kadel and Patton 1992). Limited resources require trade-offs between surveys in many study areas for a short time each or surveys in few areas for longer periods.

Because of resource limitations, in 1992 the Florida Department of Environmental Protection began shifting its emphasis from these surveys to the improvement of techniques. However, this temporary moratorium on new surveys of distribution by the department is not without costs. Long-term monitoring is probably needed to assess changes in populations and habitat use. At least, additional distribution data are probably needed on a rotating schedule, perhaps every 5 years, to update data used for the protection of manatees. Many existing data are now older than 5 years, and additional distribution information may soon be required.

Surveys of Manatee Aggregations in Winter

In winter, Florida manatees are forced to travel to warm water because of the low water temperatures in much of the state (*Lefebvre and Frohlich 1986; Reid et al. 1991;

Ackerman et al. 1995; Reid et al. 1995). Manatees migrate either far to the south (e.g., Dade, Monroe, and Collier counties), to a few natural springs (principally the Crystal River and Blue Spring), or to industrial warm-water effluents (Fig. 2). Aggregations in these areas allow the counting of large numbers of manatees from the air with relatively short, concentrated efforts. Some long-term studies provided information on trends in the sizes of these aggregations. Best results should be obtained from a regional population that aggregates in one small area where clear water allows accurate counting.

Objectives

Surveys of manatee aggregations in winter serve to determine the changing numbers of the animals at warm-water sites. Surveys may also be useful for assessing trends in counts. These objectives are primarily useful for measuring progress toward long-term recovery goals. However, these surveys are also valuable for management, such as defining boundaries of seasonal sanctuaries to protect manatee aggregations in winter. Intensive counts were made at aggregation sites in winter as early as 1967 (Hartman 1979). These counts allow the economical counting of a high proportion of all animals in a large region. Long-term studies have been made at the Crystal River, at Blue Spring, and at power plants on the eastern coast and near Fort Myers. These surveys were initially used to determine the number of manatees near aggregation sites throughout the year but later were focused on counts only in winter.

Procedures

Surveys of manatees at power plants on the eastern and southwestern coasts of Florida have been conducted from 1977 to the present (*Rose and McCutcheon 1980; *Raymond 1981; *McGehee 1982; Reynolds and Wilcox 1985, 1986, 1994; *Reynolds 1993, 1994). These surveys were a part of larger research to determine the year-round distribution and abundance of manatees. Surveys were funded by the Florida Power and Light Company. Surveys took place at six major power-generating stations, including five Florida Power and Light Company plants and one Orlando Utility Commission plant (Fig. 2) and their adjacent waters. Manatees were surveyed at several other sites, including smaller power plants at Fort Pierce and Vero Beach and in the Hobe Sound area. Areas within about 8 km of each power plant were included in surveys of manatees (*Rose and McCutcheon 1980; Reynolds and Wilcox 1994) with intensive-area methods (*Packard 1985). Water clarity, general visibility, air traffic problems, and attractiveness to manatees varied among sites.

Details of survey timing and methodology were provided by Rose and McCutcheon (*1980), *Raymond (1981),

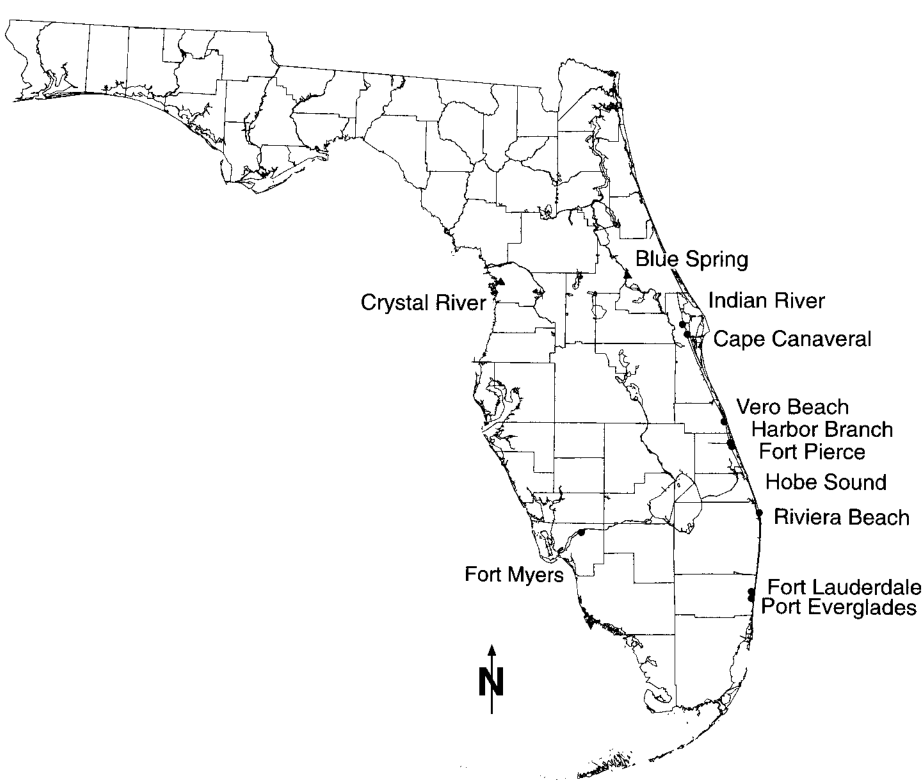

Fig. 2. Warmwater sites in Florida that manatees (*Trichechus manatus latirostris*) frequented in winter. Symbols indicate natural springs (*triangles*) and power plants (*circles*) that were included in surveys by the Florida Power and Light Company in winter.

*Packard and Mulholland (1983), and Reynolds and Wilcox (1985, 1986, 1994). Surveys of manatees at power plants were initially 2-day surveys in each week in winter and 2/month in summer. In 1980, these were reduced to 1-day surveys in each week in winter. By 1982 a schedule was achieved that consisted of 4–10 flights each year, only after winter cold fronts. Except for scheduling, the same survey methods have been used since 1977, and the same biologist has conducted the surveys since 1982. This is the longest series of available counts of manatees on the eastern and southwestern coasts of Florida.

Results

Following the suggestions of Eberhardt (*1982), Packard and Mulholland (*1983) conducted preliminary statistical analyses of the survey counts during 1977–82. They attempted to adjust or correct the counts at each power plant, based on air and water temperatures (*Packard and Mulholland 1983; *Packard et al. 1984). Their analyses showed complex relations between the counts at each plant and air and water temperatures and other environmental factors, but counts could not be adjusted for these factors. The numbers of manatees at each plant increased from fall to winter but were highly variable at each plant between consecutive flights and among years. Cold fronts caused manatees to aggregate at certain plants, resulting in high counts. More manatees stayed near the plants on cold days but dispersed from the plants on warmer days to feed. More recent studies with telemetry revealed that some manatees migrate farther southward during the coldest part of the winter, moving among southern plants for a few days, then migrating back northward in spring (Reid et al. 1991, 1995).

The highest summation of counts of manatees at all eastern coast power plants on a single date each winter showed an upward trend (linear regression, $r^2 = 0.39$, $n = 17$, $P = 0.01$; Fig. 3). Annual high counts at the Fort Myers plant were too variable to show a trend ($r^2 = 0.01$, $n = 17$, $P = 0.78$; Fig. 4). However, without correcting for short-term and long-term temperature effects on counts, the annual high counts did not reveal convincing trends (Figs. 3 and 4).

Garrott et al. (1995) improved trend information from data from the surveys at power plants during 1982–91 by developing statistical models that adjust the counts based on short-term and long-term air and water temperature patterns. The adjusted counts in 1982–91 at the power plants on the Atlantic Coast of Florida significantly increased when corrected for temperature. This suggested but did not prove that the actual size of the Atlantic Coast manatee population also increased. The adjusted counts at the Fort Myers plant did not show a significant trend.

Problems and Limitations

The percentage of manatees that is in aggregations in winter to be counted at any given time and the percentage of animals that are actually observed are not known (*Eberhardt 1982; *Packard 1985; Lefebvre et al. 1995). These counts are the only long-term data from the eastern-coast and southwestern aggregation sites, and considerable effort is justifiable to develop an index to past and future population-size trends from these data (*Packard 1985; Packard et al. *1984, 1986, 1989). An increase in knowledge of factors that influence these counts is important. Analysis of counts with telemetry data on locations and behavior of manatees by the area (Reid et al. 1995) and air and water temperatures may provide further information for correcting for possible biases in these counts.

Synoptic Survey

The synoptic survey is designed to obtain statewide counts of manatees in all winter habitats at one time. De-

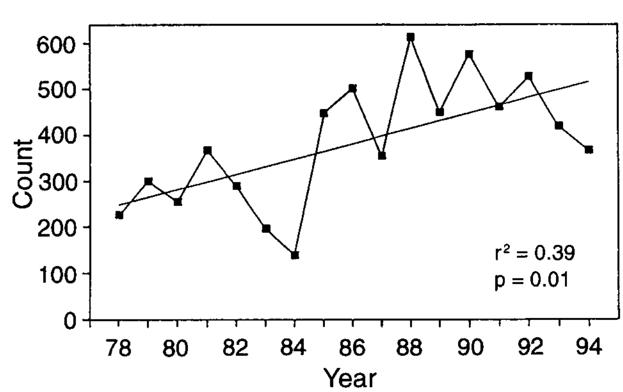

Fig. 3. Largest numbers of manatees (*Trichechus manatus latirostris*) in aggregation areas at power plants on the eastern coast of Florida, 1977–1994. Data were collected during aerial surveys in winter (Reynolds and Wilcox 1994 and sources therein). Data from 10 power plants were combined.

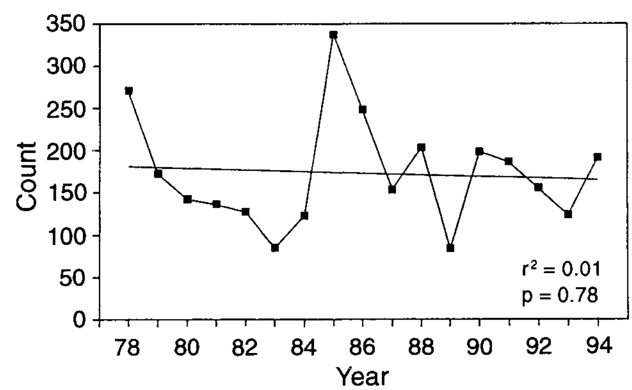

Fig. 4. Largest numbers of manatees (*Trichechus manatus latirostris*) at the Fort Myers power plant, Lee County, southwestern Florida, 1977–1994. Data were collected during aerial surveys in winter (Reynolds and Wilcox 1994 and sources therein).

scriptions of the synoptic survey have not been published. This procedure combines some features of the intensive counts of manatees in aggregations in winter and extended-area surveys of manatee distribution. The goal is to obtain the highest, presumably most accurate count, which then serves as a new baseline to evaluate indexes from other surveys. Plans were initially made by the Florida Department of Environmental Protection to conduct a synoptic survey in 1989. Surveys were not made until 1991, however, because of the lack of weather patterns suitable for synoptic surveys in 1989 or 1990. In 1990, the Florida State Legislature mandated "an impartial scientific benchmark census of the manatee population to be conducted annually" by the Florida Department of Environmental Protection (Florida Statute §370.12.5a). The subsequent synoptic surveys were made to comply with this mandate.

Procedures

The term *synoptic* was used to designate comprehensive coverage of a large area at one time. Plans were made to cover the entire potential winter range of manatees in Florida and in southeastern Georgia in 2 days (Fig. 1). Most routes followed those of recent surveys, principally over rivers, estuaries, bays, streams, and canals along most of the coastline of peninsular Florida. Most aircraft were Cessna 172's, although in a few areas manatees were surveyed from helicopters. Ground-based observers searched Blue Spring and two industrial sites in southeastern Georgia where vertical visibility was poor. Planes flew at an altitude of 150 m and at a speed of 130 km/h. Transects were used to cover some wider areas. These methods were flexible and were altered in some cases to accommodate local conditions. Routes were planned and teams were on standby for 2 months each winter. Each count was planned to follow two cold fronts or a prolonged cold period in January or February when manatees were concentrated at warm-water aggregation sites and when the winter migration was probably completed. The desired weather pattern usually was forecast with only 2–3 days notice, which made planning difficult.

Manatees on the eastern coast of Florida were surveyed on the first day and on the western coast on the second day. Surveys required nearly simultaneous counts by biologists from numerous agencies. Whenever possible, manatees in adjacent areas were simultaneously surveyed to minimize the effects on counts from manatee movements between areas. The survey was made on 2 days because of the limited number of available biologists and aircraft. Movement of manatees between the eastern and western coasts was assumed to be minimal (O'Shea 1988). Counts of manatees in all areas were tallied, and possible duplicate counts were eliminated by taking into consideration the manatees' mapped positions and the distance the manatees may travel in the elapsed time between adjacent surveys.

Synoptic surveys of manatees were conducted three times, twice in 1991 and once in 1992. Following successful surveys in 1991, the flight window in 1992 was shortened to the period from early January to mid-February, and planned coverage was reduced in a few areas. After 1991, surveys conducted north of Tampa on the western coast and north of Fort Pierce on the Atlantic Coast covered only warm-water aggregation sites. This reduced the number of teams and the cost. Few manatees were in the omitted areas during the two previous surveys. Conditions on the most recent survey in 1992 were more conducive to higher counts of manatees than during previous synoptic surveys. A significant cold front passed across Florida on 14 January 1992, and a second on 16 January. Weather conditions were good; several weeks of cool weather were followed by several days of steadily decreasing temperatures. The survey was conducted during 17–18 January; the weather was clear and cold and winds diminished in most areas. Counts were made on 21 survey routes. Ten aircraft flew simultaneously on the first day, nine on the second day. Surveys were not conducted during the winters of 1992–93 or 1993–94 because of weather conditions.

Results

Two surveys were completed in 1991 (23–24 January and 17–18 February). Counts during the first survey were 679 manatees on the eastern coast and 589 on the western coast or a total of 1,268 manatees (8.6% calves; Table 2). A second survey was conducted during 17–18 February 1991. Weather had been warm for almost a month, and a strong cold front passed on 15 February. A total of 1,465 manatees (8.8% calves) was seen, 813 on the eastern coast and 652 on the western coast. This was about 20% more than in any

Table 2. Counts of Florida manatees (*Trichechus manatus latirostris*) from synoptic aerial surveys on the eastern and western coasts of Florida, 1991–1992.

Date	Eastern	Western	Total	Percent calves	Number of Teams	Number of Observers
23–24 Jan 1991	679	589	1,268	8.6	27	32
17–18 Feb 1991	813	652	1,465	8.8	27	32
17–18 Jan 1992	907	949	1,856	8.7	21	28

previous statewide count (Table 2). During both surveys, almost all of the manatees seen in the northern part of the state were at warm-water aggregation sites (Table 3). During the second survey in the southern part of the state, about half were away from warm water (Table 3), particularly in the southeast.

The largest number of Florida manatees ever recorded was seen during the synoptic survey during 17–18 January 1992. A total of 1,856 manatees (8.7% calves) was counted, 907 on the eastern coast (7.6% calves) and 949 on the western coast (9.6% calves; Tables 2–4; Fig. 5).

Problems and Limitations of the Synoptic Survey

The synoptic surveys provided new information on the minimum size of the manatee population in Florida: 1,856 manatees in January 1992. Until that time, only 1,200 were known to exist. The greatest value of the surveys may be as a snapshot of the whole state population at once, reducing the possibility of movements among areas between adjacent count segments. However, these counts seem to be highly variable among surveys, depending on weather conditions. Weather conditions will never be optimal in all areas at once, and counts in some areas may be maximized under opposite weather conditions. In several areas, higher counts were obtained on dates other than during synoptic surveys. Optimal conditions are difficult to predict, and the best conditions in each winter are easily missed. Surveys were not conducted during some winters because of inadequate weather conditions. The results are not statistical estimates of population size and will probably not provide estimates of population-size trends. They are more costly than many other surveys because of the required large number of aircraft and biologists and the large amounts of coordination.

Population Size and Size Trends

Trends Based on Surveys of Aggregations in Winter

Crystal River Area

Aerial surveys of manatees have been conducted in the Crystal River region in winter since 1967, except during the three winters from 1970–71 to 1972–73. Surveys covered the Crystal and Homosassa rivers and surrounding areas (Hartman 1979; *Powell 1981; Powell and Rathbun 1984; Kochman et al. 1985; Rathbun et al. 1990; Chassahowitzka National Wildlife Refuge, unpublished data). These are the only aggregation sites in winter in northwestern Florida and are characterized by clear water. This area is largely isolated in winter from other aggregation sites; however, counts and distribution in the Crystal River area markedly change during and between winters. Animals leave on feeding excursions, and changes in counts can be substantial from week to week (Rathbun et al. 1990).

I used exponential regression to examine maximum aerial counts in each winter from 1967 to 1994 for trends. Maximum aerial counts each winter in the Crystal River area were based on data from Hartman (1979), Powell (*1981), Powell and Rathbun (1984), Rathbun et al. (1990), and unpublished data of the Chassahowitzka National Wildlife Refuge. Exponential regression was used because populations often change exponentially and because it allows simpler expression of the annual percentage change in numbers. The formula for exponential regression is

$$y = a \times e^{bt} \quad (1)$$

where y is the count, t is the year, and a and b are regression coefficients (Eberhardt and Simmons 1992). This is equivalent to the linear regression form

$$\ln(y) = \ln(a) + bt \quad (2)$$

This further gives

$$\text{annual percent change} = (e^{b} - 1) \times 100\%. \quad (3)$$

Manatee counts in the Crystal River area showed a significant upward trend with low variability (Fig. 6; +9.7%/year; $r^2 = 0.93$, $n = 23$, $P < 0.001$). Maximum counts increased from 38 during 1967–68 to 292 during 1992–93. Similarly, the total number of manatees identified during each winter (Hartman 1979; *Powell 1981; Powell and Rathbun 1984; Rathbun et al. 1990) increased through time.

Moore (1951) described manatee sightings as rare in the Crystal River area in the 1940's and earlier. Increasing populations were noted by later researchers (Hartman 1979; Powell and Rathbun 1984; *Beeler and O'Shea 1988; O'Shea 1988; Rathbun et al. 1990). Life-history studies of known individuals suggested that most of this increase could

Table 3. Percentage of Florida manatees (*Trichechus manatus latirostris*) at warm-water sources during synoptic surveys in northern and southern zones of Florida, 1991.

Date	Northern zone	Southern zone	Statewide
23–24 Jan 1991	93	7	53
17–18 Feb 1991	97	47	85

Table 4. Synoptic aerial survey of Florida manatees (*Trichechus manatus latirostris*) in Florida and Georgia, 17 (eastern and coast) 18 (western coast) January 1992, unless otherwise noted.

Location of survey	Total number of manatees	Number of calves	Comments
Eastern coast			
Camden/Glynn counties, Georgia	5	0	Count from shore at four industrial plants
Nassau/Duval counties	2	0	Five industrial plants and vicinity
St. Johns/Flagler/Volusia counties	0	0	Conducted 18 Jan
Volusia County (St. Johns River) Blue Spring Run	67	7	Count made from canoe
Brevard County			Aerial counts at power plants, warm-water sites, known use areas, and immediate vicinity
OUC plant	122	[a]	
Cape Canaveral plant	59	[a]	
Indian River County			
Vero Beach plant	23	2	
Other sites	32	4	
St. Lucie/Martin counties			
Fort Pierce plant	20	3	
Other sites	20	[a]	
Palm Beach County			
Riviera Beach plant	245	15	
Other sites	38	4	
Broward County			
Port Everglades plant	167	8	Survey using helicopter
Fort Lauderdale plant	7	0	
Other sites	5	0	
Dade County	86	11	Survey using helicopter
Monroe County (Florida Keys)	9	1	
Eastern total	907	55	
Western coast			
Citrus/Levy counties	260	24	
Western Tampa Bay	15	0	
Eastern Tampa Bay	111	13	
Manatee/Sarasota counties	2	0	
Sarasota/Charlotte counties	17	3	
Charlotte/Lee counties	190	20	
Lee/Collier counties	246	22	
Monroe County (western Everglades)	77	7	
Monroe County (eastern Everglades)	29	2	Conducted 17 Jan
Okeechobee Waterway/Lee/Hendry/ Glades/ Okeechobee/Martin/ Palm Beach counties	2	0	Conducted 17 Jan
Western total	949	91	
Grand total	1,856	146	

[a] Calf counts were not obtained at three sites.

result from reproduction and survival of resident manatees (Eberhardt and O'Shea 1995), but some of the increase probably also resulted from permanent immigration by adults from areas farther south and recruitment of their descendants (Powell and Rathbun 1984; O'Shea 1988; Rathbun et al. 1990; Rathbun et al. 1995). At the Crystal River, food supplies are abundant, unlike at most other winter aggregation sites (Hartman 1979; O'Shea 1988), and increases in manatee numbers in the region have been attributed in part to the introduction of exotic aquatic vegetation in the mid-1960's (Hartman 1979; Powell and Rathbun 1984; O'Shea 1988).

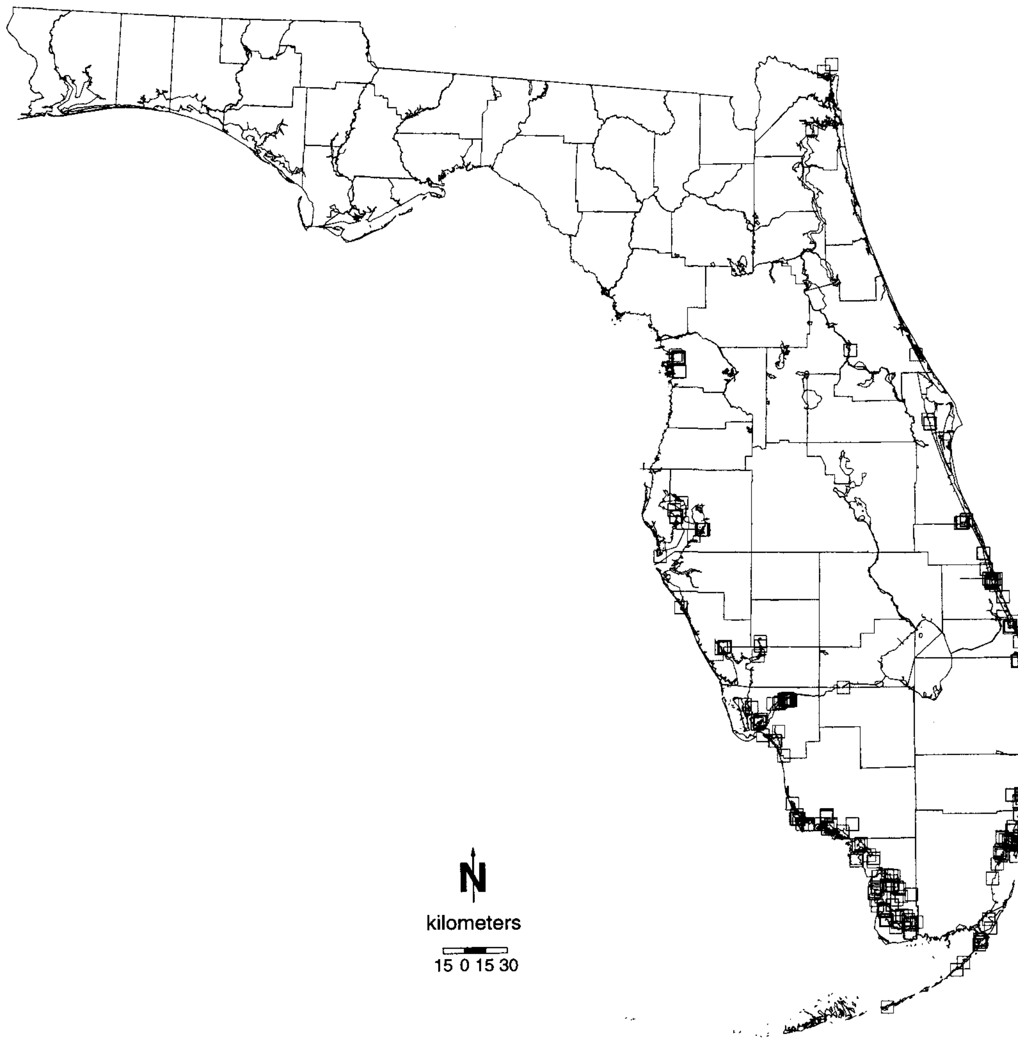

Fig. 5. Locations of 1,856 manatees (*Trichechus manatus latirostris*) seen during the third synoptic aerial survey in Florida and in southeastern Georgia, 17–18 January 1992. Each symbol indicates one group.

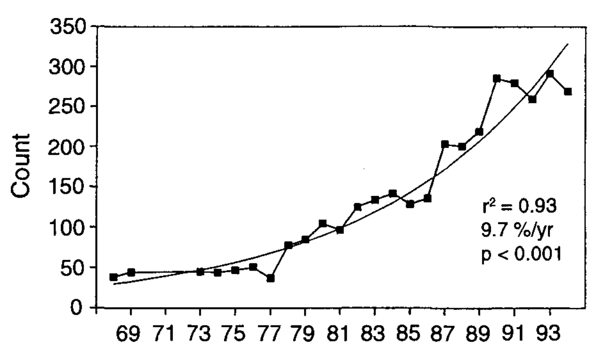

Fig. 6. Trend (exponential regression) in counts of Florida manatees (*Trichechus manatus latirostris*) made during aerial surveys at winter aggregation sites in the Crystal River area, Citrus County, 1967–1994. Highest count obtained during each winter is shown. Data were collected by Hartman (1979), Powell (*1981), Powell and Rathbun (1984), Rathbun et al. (1990), and the Chassahowitzka National Wildlife Refuge (unpublished data).

Blue Spring

Counts of manatees at the aggregation site at Blue Spring State Park provide the only long-term trend data about manatees in the St. Johns River. The spring run is shaded by a tree canopy, and aerial surveys are therefore not practical. However, the clear water allows accurate counts from canoes and shore, and all individuals are identifiable (T. J. O'Shea, National Biological Service, Fort Collins, Colorado, personal communication). Counts have been conducted almost daily in winter since 1970 except during the winters of 1972–73 and 1973–74. Analysis of the total number of manatees identified during each winter was based on data obtained from Hartman (1979), Powell and Waldron (*1981), O'Shea (1988), T. J. O'Shea (National Biological Service, Fort Collins, Colorado, personal communication), and W. C. Hartley (Florida Park Service, Orange City, Florida, personal communication).

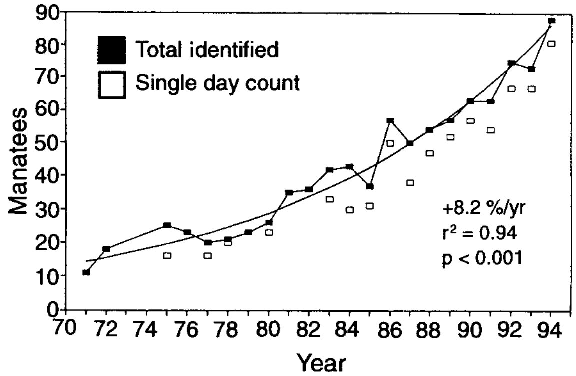

Fig. 7. Trend (exponential regression) in counts (highest total number of animals identified during each winter) of Florida manatees (*Trichechus manatus latirostris*) at the winter aggregation site in Blue Spring State Park, Volusia County, 1970–1994. Highest counts of manatees on a single day each winter at Blue Spring are also shown. Data were collected during surveys by canoe and snorkeling by Hartman (1979), Powell and Waldron (*1981), O'Shea (1988) and the National Biological Service and Florida Park Service (unpublished data).

The number of manatees identified at Blue Spring each winter showed an upward trend with low variability (+8.2%/year; $r^2 = 0.94$, $n = 22$, $P < 0.001$; Fig. 7), increasing from 11 during 1970–71 to 88 during 1993–94. Similarly, highest single-day counts each year increased from 11 during 1970–71 to 81 during 1993–94 (+8.7%/year; $r^2 = 0.96$, $n = 19$, $P < 0.001$).

Increases in counts at Blue Spring were discussed by Beeler and O'Shea (*1988), O'Shea (1988), O'Shea and Hartley (1995) and O'Shea and Langtimm (1995). Studies of known individuals showed that most of this increase resulted from reproduction and survival of resident animals, but part was also from permanent immigration of adults (O'Shea 1988). A maximum of about one-third of the increase in counts at Blue Spring may be due to immigration and subsequent reproduction by the immigrants (T. J. O'Shea, National Biological Service, Fort Collins, Colorado, personal communication). Forty-two of the 63 manatees identified at Blue Spring during the 1990–91 winter season were present during the first 3 years of intensive study (winters 1978–79 through 1980–81, $n = 14$ animals) or were descendants ($n = 28$) of those animals. The remaining 21 were immigrants or their offspring. Therefore, during a 10-year period, 67% of the net population growth was from internal recruitment (T. J. O'Shea, National Biological Service, Fort Collins, Colorado, personal communication). This is a minimum estimate because some individuals identified as new immigrants could have been offspring of long-term residents that returned when older but were no longer identifiable as such because of new marks. O'Shea and Langtimm (1995) found high adult survival at Blue Spring. Eberhardt and O'Shea (1995) estimated positive population growth rates at Blue Spring based on demographic data and discussed results in relation to trends in counts. Manatees at Blue Spring have been increasingly protected from direct injury from watercraft and from disturbance by boats, swimmers, and divers (Hartman 1979; *Powell and Waldron 1981; *Beeler and O'Shea 1988; O'Shea 1988). This increased protection may have encouraged more manatees to use these aggregation sites.

Tampa Bay

Weigle et al. (*1988) summarized the highest annual aerial counts of manatees obtained in the Tampa Bay area from 1979 to 1986, and no counts exceeded 76 manatees. Subsequently, counts of manatees during surveys during the winters of 1987–94 were as high as 190 (24 January 1994; *Reynolds et al. 1991; Florida Department of Environmental Protection and Eckerd College, unpublished data). However, major changes also occurred in warm-water sources in the 1980's (*Weigle et al. 1988). The Gardinier Phosphate Plant discharge into the Alafia River ceased in 1986, and a small no-entry zone was created at the Tampa Electric Company's Big Bend plant in 1986 and expanded to the entire discharge canal in 1989 (*Reynolds et al. 1991). These actions probably reduced disturbance to manatees from boats and resulted in a shift in manatee use from the Alafia River to the Big Bend plant during 1985–86 (*Weigle et al. 1988). The increasing levels of protection may have encouraged manatees to immigrate from other wintering areas, although this has not so far been detected by studies with telemetry (*Lefebvre and Frohlich 1986; B. L. Weigle, Florida Department of Environmental Protection, St. Petersburg, Florida, unpublished data) or scar catalog studies (Beck and Reid 1995; B. L. Weigle, Florida Department of Environmental Protection, unpublished data). The number of documented manatee deaths is low in the Tampa Bay area (O'Shea et al. 1985; *Reynolds et al. 1991; Ackerman et al. 1995). Manatee sightings were apparently rare in the Tampa Bay area until the 1950's (Moore 1951), and numbers seemingly were low until the 1970's (Hartman *1974, 1979; Irvine and Campbell 1978; Irvine et al. 1982; *Beeler and O'Shea 1988).

Counts at Power Plants

Trends in counts of aggregations in winter at seven power plants on the eastern coast and at the Fort Myers plant on the western coast were presented above and by Garrott et al. (1995). These are the only long-term trend data in these areas. Results from Garrott et al. (1995) suggested that adjusted counts at the plants on the eastern coast increased but showed no evidence of change at the Fort Myers plant on the western coast. Although the number of documented deaths in both areas is relatively high (O'Shea et al. 1985; Ackerman et al. 1995), models based on demographic information suggested that past manatee population growth on the eastern coast could have occurred but, if so, at a low rate (Eberhardt and O'Shea 1995).

Trends during Warm Seasons in the Banana River

Intensive surveys of manatees during warm seasons have been made in the northern Banana River since 1977 (Shane 1983; Provancha and Provancha 1988, *1989; National Aeronautical and Space Administration, unpublished data). These are the only long-term counts during warm seasons on the eastern coast. Counts were made from an airplane during 1977–80 and from a helicopter during 1980–81 and from 1984 to the present; similar flight routes were used (Provancha and Provancha 1988). Aerial counts increased through time; the counts were highest in spring each year (Provancha and Provancha 1988, *1989; National Aeronautical and Space Administration, unpublished data). High counts in spring seemed to reflect a temporary influx of manatees in transit during spring migration (Provancha and Provancha 1988). Recent counts in spring were as high as 200–400 manatees. Counts in summer (June to August) north of the NASA Causeway from 1977 to 1981 did not exceed 30 animals (Provancha and Provancha 1988), but recent counts were as high as 139 (J. Provancha, National Aeronautical and Space Administration, Kennedy Space Center, Florida, unpublished data). Provancha and Provancha (1988) suggested that no other area on the eastern coast offers as much protected suitable habitat as the northern Banana River. Much of this area is inside the Kennedy Space Center and has been closed to boating for many years for security reasons. A larger area in the Merritt Island National Wildlife Refuge (north of the Cape Canaveral Barge Canal) was closed in 1990 for manatee protection, substantially decreasing human disturbance. Provancha and Provancha (1988) suggested two possible reasons for increased counts in the northern Banana River: increases in manatee population size and shifts in habitat use by manatees into the northern Banana River because of increased development or disturbance outside this sanctuary.

Problems and Limitations in Long-term Survey Data

Manatee populations in all areas for which long-term data exist seem to be increasing (eastern-coast power plants, Crystal River, Blue Spring, Tampa Bay, Banana River in summer) or appear stable (Fort Myers power plant). Although these data are encouraging, they do not encompass all areas, and trends may differ in populations lacking long-term data. Moreover, interpretations of increases in counts over time are difficult because of various confounding factors (Reynolds and Wilcox 1994; Garrott et al. 1995). Although the increasing counts in most areas where manatees were surveyed suggested that populations increased, alternative explanations exist. Manatees are able to locate and use protected areas. Manatees may have increased use of these areas and avoided other areas in response to improving resources such as availability of warm water, protection from human disturbance, and increasing aquatic plants. Manatees may have become more visible to biologists, perhaps because a higher proportion uses aggregation sites than in the past or because of improved visibility or changes in plant operations (Packard et al. 1989; Reynolds and Wilcox 1994). In most cases, different people conducted surveys, the survey procedures evolved, and skills or techniques for surveying aggregated manatees in winter may have improved. Each of these alternative explanations could also result in the observed upward trends of counts in some refugia in the absence of an actual increase in the manatee population size. Although no data support these alternative speculations on the apparent increases in counts, conclusions that populations actually increased in these parts of the state could be erroneous (Reynolds and Wilcox 1994; Eberhardt and O'Shea 1995; Garrott et al. 1995).

Statewide Population-size Estimates

A population-size estimate of Florida manatees is desirable as a baseline for estimating trends, modeling populations, and assessing the effect of observed mortality. Statewide surveys were designed to provide such a baseline. However, other than the synoptic surveys, only a small number of studies included simultaneous counts of manatees throughout the southeastern United States. Hartman (*1974) counted 255 manatees throughout Florida and southeastern Georgia in summer 1973; he used one plane during six consecutive weeks. A crude correction factor was based on water clarity (*Hartman 1974). Hartman concluded from these counts and interviews of the public that probably 800 manatees (range 750–850) were in Florida and Georgia. Counts in summer have since been lower than counts in the same general areas in winter (Irvine and Campbell 1978; Rathbun et al. 1990; *Reynolds et al. 1991). Manatees are dispersed widely in summer in small groups at low densities in unpredictable locations. Visibility is poor in many areas because of turbid water and overhanging trees.

In winter 1976, Irvine and Campbell (1978) counted 738 manatees in Florida and Georgia. Nine teams conducted surveys statewide in 6 days after a cold front. Manatees in most areas were counted simultaneously in a single day. These and other data suggested a population of at least 800–1,000 in 1978 (*Brownell et al. 1981). A survey was also conducted in August 1976 (Irvine and Campbell 1978) and included parts of the Florida panhandle, Georgia, and the Carolinas; 245 manatees were seen, similar to Hartman's (*1974) count in summer 1973. After 1976, research shifted to other topics because these mass efforts were too costly and logistically difficult and did not provide data for clear interpretation (*Eberhardt 1982; G. B. Rathbun, National Biological Service, San Simeon, California, personal communication).

High counts at power plants in January 1985 and counts in other areas of the state led experts to revise the minimum statewide estimate to 1,200 in 1985 (O'Shea 1988). However, surveys were not made at the same time in all areas, and manatees in some important areas had not been counted at all in several years. A record single-day count of 717 manatees at selected power plants was made under favorable counting conditions in January 1986, and a higher count of 804 in February 1988 (Reynolds and Wilcox 1994). In December 1989, a composite of counts in various areas during a short time period revealed 1,240 manatees (B. B. Ackerman, Florida Department of Environmental Protection, St. Petersburg, Florida, unpublished data). As discussed above, the synoptic survey in January 1992 revealed a count of 1,856.

Interpretation of the results of these statewide surveys is difficult. In 19 years the best minimum estimate increased from 800 to 1,856, but these data were obtained with survey methods that differed in several important ways. O'Shea (1988) reviewed statewide manatee population counts through 1985. He found no firm evidence of a decrease or increase in manatee populations in spite of the increase in the official minimum estimate because the methods were without a measure of precision.

What does the record count of 1,856 in January 1992 reveal about trends in the statewide manatee population? Perhaps not much. Even though the best minimum counts increased from 800 in 1973 to 1,000 in 1978, to 1,200 in 1985, and to 1,856 in 1992, a basis to determine the statistical significance does not exist (*Eberhardt 1982; O'Shea 1988). Previous surveys were not over as large an area, under as good conditions, as comprehensive, or in as short a time as the 1992 synoptic survey.

This higher count does not provide evidence that the population is no longer endangered. Rescaling to a new baseline does not change the fact that mortality from various anthropogenic causes is still increasing and that these threats may be greater than the population can withstand (*Brownell et al. 1981; O'Shea 1988; Marmontel 1993; Ackerman et al. 1995; Eberhardt and O'Shea 1995). Accurate assessment of the effects of anthropogenic mortality on the manatee population is not yet possible. Therefore, higher statewide counts provide no reason to relax conservation. In the interim, however, methods of statewide surveys must be improved. Goals should be to use statistical sampling methods to reduce the required effort in a wide-scale survey, provide statistically meaningful estimates with confidence limits, correct for counting biases, and reduce the total cost (Lefebvre et al. 1995).

Research to Improve Survey Techniques

Techniques for estimating population sizes of Florida manatees are currently inadequate (*Eberhardt 1982; Packard et al. 1985, 1986; O'Shea 1988; *Reynolds and Gluckman 1988; *U.S. Fish and Wildlife Service 1989; Lefebvre and Kochman 1991; Lefebvre et al. 1995). No basis exists to statistically measure trends in population size, correct for visibility errors (visibility bias), or assign confidence levels to minimum counts (*Eberhardt 1982; *Packard and Mulholland 1983; Packard et al. *1984, 1986; *Packard 1985; Lefebvre et al. 1995). The number of manatees cannot be estimated from a random sample of current surveys. The estimated number of manatees in one subunit cannot be extrapolated to other subunits. Counts are not corrected for visibility bias. The current survey procedures probably lead to an underestimation of the number of manatees and do not provide estimates of the precision of the count (i.e., standard deviation).

Research to Determine Visibility and Absence Bias

Visibility bias (the proportion of missed animals) is one of the largest problems in estimating manatee population sizes (Lefebvre et al. 1995). Visibility bias in aerial counts of other animals was determined with known or marked subpopulations (Eberhardt et al. 1979; Pollock and Kendall 1987). The proportion of a known number of radio-tagged animals observed during counts has also been used to estimate bias in various species of large mammals (Floyd et al. 1979; Gasaway et al. 1985; Packard et al. 1985, 1989; Samuel et al. 1987; Ackerman 1988). Other researchers used known subpopulations comprising groups monitored intensively by another method or from the ground (*Hartman 1974; Samuel and Pollock 1981) or known numbers of penned animals (Packard et al. 1989; Unsworth et al. 1990). Accurate counts are needed to obtain correction factors (Eberhardt et al. 1979; *Eberhardt 1982; Pollock and Kendall 1987). Correction factors were developed for counts of other species—some terrestrial—and were based on group size, behavior, and habitat (Eberhardt et al. 1979; Floyd et al. 1979; Samuel and Pollock 1981; Gasaway et al. 1985; Samuel et al. 1987; Ackerman 1988; Marsh and Sinclair 1989b).

Packard et al. (1985) investigated visibility bias in surveys of manatees in the St. Johns River based on known numbers of radio-tagged and unmarked manatees near Blue Spring. Many manatees were not seen in these turbid waters; an estimated 38–47% were seen. The seen proportion varied by river, lake, and creek habitats. The radio tags were often not visible from aircraft when the peduncle was submerged. Packard et al. (1989) investigated visibility bias in winter near Fort Myers with telemetry. Floating transmitters used then were not easily seen from aircraft (*Packard 1985; Packard et al. 1989). These researchers did not determine the environmental variables that correlate with visibility or suitable correction factors for current surveys.

However, as recommended by Lefebvre et al. (1995), additional assessment of visibility bias is underway. Preliminary tests of visibility bias in aerial counts of manatees were made by the Florida Department of Environmental Protection and collaborators during 1990–92 with radiotelemetry and are planned for the future. Analysis of data will be made with logistic regression to identify variables (covariates) that influence the probability of seeing a given group of manatees. Significant variables will be used to develop an equation (visibility model) to predict the probability of seeing groups under various environmental conditions. This equation can then be converted to a visibility correction factor (Samuel et al. 1987; Ackerman 1988; Steinhorst and Samuel 1989) on a group-by-group basis. Success of this approach depends on the visibility of the tags from the air (*Packard 1985; Pollock and Kendall 1987).

A different approach to estimating the number of animals missed in surveys is a double-sampling technique (Pollock and Kendall 1987; Marsh and Sinclair 1989b; Marsh 1995). Paired observers view the same area, and each counts and maps seen animals. The number of animals seen by each observer is determined, and mark–recapture statistics are used to estimate the number of objects missed by both observers. This provides an estimate with confidence limits of the total number of objects in the surveyed area. When animals are in groups, the number of groups is estimated and is multiplied by the average group size to provide the total number of present animals (Marsh and Sinclair 1989b; Marsh 1995). Correction factors are based on seen or missed groups—not individuals—because sightings of members in a group are not considered independent. Double-observer counts were tested during monthly aerial surveys of manatee distributions in Tampa Bay during 1989–92 (*Reynolds et al. 1991; B. Ackerman, Florida Department of Environmental Protection, St. Petersburg, Florida, unpublished data) and will be made in the future.

Telemetry data can also be used to investigate absence bias in determining whether manatees are present in the survey area as expected (Packard et al. *1984, 1989; Marsh and Sinclair 1989b; Lefebvre et al. 1995; Marsh 1995). For example, locations of radio-tagged animals can be used to estimate the proportion of all animals available to be counted at power plants on a given day.

Use of Novel Approaches

Lefebvre et al. (1995) suggested that standardized surveys during warm seasons should be tested as supplements to counts in winter. Short-term weather patterns probably affect the density of manatees less in summer than in winter. Therefore, counts during warm seasons with a standardized procedure and during a short time period should provide more consistent data for determining annual indices and population-size trends. Strip transects have been used for population-size estimates of dugongs (*Dugong dugong*; Marsh and Sinclair 1989a, 1989b; Marsh 1995) and other species (Eberhardt et al. 1979; Pollock and Kendall 1987; Barlow et al. 1988; Graham and Bell 1989). Strip transects were used for counting bottlenosed dolphins (*Tursiops truncatus*) and manatees in the Indian and Banana rivers, (Leatherwood 1979), but manatee counts were incidental and were not used for calculating estimates. Transects are most suitable in large, homogenous areas. The Florida Department of Environmental Protection and the National Biological Service recently selected three areas—Charlotte Harbor, Ten Thousand Islands, and the Banana River—to test a strip transect methodology for counting manatees in warm seasons. This work was initiated in 1992 and is in progress.

Ongoing research also includes the use of other novel approaches. Recent test flights were conducted to compare counts from an airship and from an airplane, namely a Cessna 172 and the Airship Shamu. The airship is provided by Sea World of Florida and has a length of 58 m and a capacity for two pilots and five passengers. The flights were made over three Tampa Bay power plants and adjacent areas on 12 December 1990 and on 22 and 25 January 1992. Additional flights were made in 1993. The airship was flown along discharge canals and transects across adjacent water bodies. Observers looked out of large, open windows on either side of the airship. Altitudes were usually 150 m but also 20–300 m. Ground speed was 0–15 km/h. Because of the stability and slow speed of the airship, observers were able to use binoculars, long telephoto lenses on still cameras, and video cameras. Preliminary flights demonstrated the usefulness of an airship for counting manatees, although counts from the two aircraft were similar. Manatees had less reaction to the airship than to an airplane. This allowed investigators to observe manatees without repeatedly circling in a small plane or disturbing the animals with the noise and turbulence from a helicopter.

Large airships may not be as effective for surveys of manatee distributions because they are not as maneuverable as an airplane. However, comparisons of the two aircraft must be made to determine the strengths and weaknesses of each kind of aircraft for various tasks. I recommend additional testing of airships. Smaller, more maneuverable and more affordable airships may soon be available for extended observation.

Other technologies are probably useful for aerial surveys of manatees. High-resolution aerial video may be used to record sightings on long transects for later viewing and counting and simultaneous documentation of water conditions (Sidle and Ziewitz 1990). Computer-image analysis may be available for detecting and counting manatees on videotapes and for measuring body lengths (Ratnaswamy and Winn 1993) and quantifying visibility conditions. Use of global positioning systems will improve accuracy of sighting locations and will accurately record the flight path to document the exact areas covered during flights. Advances in sonar may allow accurate detection of manatees in some small areas where aerial counting of the manatees is difficult; counts on the ground could provide verification of counts from aircraft. Sensitive time-depth recorders (Goodyear 1993) may be used to document when manatees are at the surface and to improve correction factors. Previously classified, military remote-sensing technology may eventually be used to detect and count marine mammals with various platforms (military satellites, high-altitude reconnaissance planes, or unoccupied military drones with video or real-time artificial intelligence algorithms) in large areas.

Conclusions

Recommendations for improvements in aerial survey methods periodically have been made (*Eberhardt 1982; *Packard 1985; Packard et al. 1986; Lefebvre et al. 1995). Improvements were made, but progress has been slow. Most survey methods are the same as 10–15 years ago. Surveys of distribution have been made in almost all areas of Florida that manatees use substantially. These data are in demand for developing protection of manatees, particularly for planning boat traffic regulations and coastal development. Long-term, regular monitoring of manatees may be necessary to update distribution data and to reassess manatee protection needs.

The January 1992 synoptic survey revealed more manatees than had ever been recorded. However, the method is not adequate to track statewide trends, and a more standardized method is needed. Counts from future surveys will probably be as variable as those from the three surveys in 1991 and 1992. Estimated population sizes based on surveys at aggregation sites in winter increased in several areas of the state where long-term studies were made, but the trends in population sizes in other areas are unclear. Proposed techniques for monitoring trends must include tests of their statistical power to detect small changes (Gerrodette 1987; Taylor and Gerrodette 1993).

Improvement of aerial-survey techniques is a high priority in manatee-population research. Statistically valid techniques are needed. Development of correction procedures for visibility bias is continuing. These new techniques probably require advanced statistical analyses, more observers in the aircraft, more intensive survey effort, and more funds. Assessment of trends may require more replication of surveys within years.

Recent advances in electronic equipment and computers will make the data more usable. Examples include use of a global positioning system to more accurately record the locations and geographic information system mapping techniques and sighting density maps to display the results. Small airships may improve surveys.

Acknowledgments

Most aerial surveys by the Florida Department of Environmental Protection were funded by the Florida Department of Environmental Protection Save the Manatee Trust Fund with sales of Save the Manatee auto license tags. Additional funding was provided by the Save the Manatee Club. Many biologists from the Florida Department of Environmental Protection and other agencies, universities, and private research laboratories participated in these surveys during many years. Various agencies generously provided data from aerial surveys for the Florida Department of Environmental Protection Marine Resources Geographic Information System.

The synoptic surveys were conducted with the cooperation of biologists from many agencies and groups. Synoptic-survey flight expenses were paid by participating agencies or by the Florida Department of Environmental Protection. Additional funding was provided by R. Boone of Chevron, Inc., the Save the Manatee Club, and the Florida Power and Light Company. The following agencies and individuals participated during 1991 or 1992: the Florida Department of Environmental Protection (K. Abbott, B. Ackerman, B. Beeler, M. Clemons, K. Curtin, K. Frohlich, W. Hartley, M. Justice, J. Kenner, C. Knox, D. LaGrua, R. Mezich, M. Morris, P. Nabor, J. Serino, S. Tyson, J. Valade, B. Weigle, P. Wells, A. Welty, and E. Westerman), the St. Johns River Water Management District (J. Higman), the Georgia Department of Natural Resources (M. Harris), Brevard County (R. Day and J. Snodgrass), Broward

County (D. Burgess and D. Stone), Dade County (S. Markley and K. Mayo), Palm Beach County (D. Carson), the U.S. Fish and Wildlife Service (F. Drauszewski, J. Kleen, S. Marcus, and R. Quarles), the National Biological Service (R. Bonde, L. Lefebvre, and J. Reid), Everglades National Park (S. Snow), the Kennedy Space Center (J. and M. Provancha), Eckerd College (P. Boland and J. Reynolds), the Mote Marine Laboratory (J. Gorzelany, J. Kadel, and G. Patton), and the Save the Manatee Club (P. Thompson). Additional Florida Department of Environmental Protection and National Biological Service staff located radio-tagged manatees on the days of the surveys, entered data into computer databases, and produced geographic information system maps. I thank the pilots and crew of Sea World's Airship Shamu for making those flights possible, especially pilot A. Judd and coordinators F. Kennelly and W. Waier. N. Berill, K. Clifton, and L. Ward-Geiger of the department entered, digitized, and proofed the aerial survey sightings and produced the maps. K. Clifton, A. Huff, T. O'Shea, J. Provancha, J. Reynolds, and the Florida Marine Research Institute editorial staff provided helpful comments on the manuscript.

Cited References[2]

Ackerman, B. B. 1988. Visibility bias of mule deer aerial census procedures in southeast Idaho. Ph.D. dissertation, University of Idaho, Moscow. 106 pp.

Ackerman, B. B., S. D. Wright, R. K. Bonde, D. K. Odell, and D. J. Banowetz. 1995. Trends and patterns in mortality of manatees in Florida, 1974–1992. Pages 223–258 *in* T. J. O'Shea, B. B. Ackerman, and H. F. Percival, editors. Population biology of the Florida manatee. National Biological Service Information and Technology Report 1.

Barlow, J., C. W. Oliver, T. D. Jackson, and B. L. Taylor. 1988. Harbor porpoise, *Phocoena phocoena*, abundance estimation for California, Oregon, and Washington: II. Aerial surveys. Fishery Bulletin 86:433–444.

Beck, C. A., and J. P. Reid. 1995. An automated photo-identification catalog for studies of the life history of the Florida manatee. Pages 120–134 *in* T. J. O'Shea, B. B. Ackerman, and H. F. Percival, editors. Population biology of the Florida manatee. National Biological Service Information and Technology Report 1.

*Beeler, I. E., and T. J. O'Shea. 1988. Distribution and mortality of the West Indian manatee (*Trichechus manatus*) in the southeastern United States: a compilation and review of recent information. Document Number PB 88-207980/AS, National Technical Information Service, Springfield, Va. 613 pp.

[2] An asterisk denotes unpublished material.

*Brownell, R. L., Jr., K. Ralls, and R. R. Reeves. 1981. Report of the West Indian manatee workshop. Pages 3–16 *in* *R. L. Brownell, Jr., and K. Ralls, editors. 1981. The West Indian manatee in Florida. Proceedings of a workshop held in Orlando, Florida, 27–29 March 1978. Florida Department of Natural Resources, Tallahassee. 154 pp.

CH_2M Hill. 1986. Aerial census of manatees in the vicinity of Six Mile Creek, in the lower middle St. Johns River, Florida. CH_2M Hill, Gainesville, Fla. Report for St. Johns Harbour, Inc. Unnumbered.

*Eberhardt, L. L. 1982. Censusing manatees. Manatee Population Research Report 1, Florida Cooperative Fish and Wildlife Research Unit, University of Florida, Gainesville. 18 pp.

Eberhardt, L. L., D. G. Chapman, and J. R. Gilbert. 1979. A review of marine mammal census methods. Wildlife Monographs 63. 46 pp.

Eberhardt, L. L., and T. J. O'Shea. 1995. Integration of manatee life-history data and population modeling. Pages 269–279 *in* T. J. O'Shea, B. B. Ackerman, and H. F. Percival, editors. Population biology of the Florida manatee. National Biological Service Information and Technology Report 1.

Eberhardt, L. L., and M. A. Simmons. 1992. Assessing rates of increase from trend data. Journal of Wildlife Management 56:603–610.

*Florida Department of Natural Resources. 1989. Recommendations to improve boating safety and manatee protection for Florida waterways. Report to the Governor and Cabinet. Final report. 20 pp.

Floyd, T. J., L. D. Mech, and M. E. Nelson. 1979. An improved method of censusing deer in deciduous–coniferous forests. Journal of Wildlife Management 43:258–261.

Garrott, R. A., B. B. Ackerman, J. R. Cary, D. M. Heisey, J. E. Reynolds, III, and J. R. Wilcox. 1995. Assessment of trends in sizes of manatee populations at several Florida aggregation sites. Pages 34–55 *in* T. J. O'Shea, B. B. Ackerman, and H. F. Percival, editors. Population biology of the Florida manatee. National Biological Service Information and Technology Report 1.

Gasaway, W. C., S. D. Dubois, and S. J. Harbo. 1985. Biases in aerial transect surveys for moose during May and June. Journal of Wildlife Management 49:777–784.

Gerrodette, T. 1987. A power analysis for detecting trends. Ecology 68:1364–1372.

Goodyear, J. D. 1993. A sonic/radio tag for monitoring dive depths and underwater movements of whales. Journal of Wildlife Management 57:502–513.

Graham, A., and R. Bell. 1989. Investigating observer bias in aerial survey by simultaneous double-counts. Journal of Wildlife Management 53:1009–1016.

*Hartman, D. S. 1974. Distribution, status, and conservation of the manatee in the United States. Document Number PB 81-140725, National Technical Information Service, Springfield, Va. 246 pp.

Hartman, D. S. 1979. Ecology and behavior of the manatee (*Trichechus manatus*) in Florida. American Society of Mammalogy Special Publication 5. 153 pp.

Irvine, A. B. 1982. West Indian manatee. Pages 241–242 *in* D. E. Davis, editor. Handbook of census methods for terrestrial vertebrates. CRC Press, Boca Raton, Fla.

Irvine, A. B., J. E. Caffin, and H. I. Kochman. 1982. Aerial surveys for manatees and dolphins in western peninsular Florida. Fishery Bulletin 80:621–630.

Irvine, A. B., and H. W. Campbell. 1978. Aerial census of the West Indian manatee, *Trichechus manatus*, in the southeastern United States. Journal of Mammalogy 59:613–617.

*Kadel, J. J., and G. W. Patton. 1992. Aerial studies of the West Indian manatee (*Trichechus manatus*) on the west coast of Florida from 1985–90: a comprehensive six year study. Mote Marine Laboratory Technical Report 246. Report to Sarasota County Natural Resources Department. 39 pp. + appendixes.

Kinnaird, M. F. 1985. Aerial census of manatees in northeastern Florida. Biological Conservation 32:59–79.

Kochman, H. I., G. B. Rathbun, and J. A. Powell. 1985. Temporal and spatial distribution of manatees in Kings Bay, Crystal River, Florida. Journal of Wildlife Management 49:921–924.

Leatherwood, S. 1979. Aerial survey of the bottlenosed dolphin, *Tursiops truncatus*, and the West Indian manatee, *Trichechus manatus*, in the Indian and Banana rivers, Florida. Fishery Bulletin 77:47–59.

Lefebvre, L. W., B. B. Ackerman, K. M. Portier, and K. H. Pollock. 1995. Aerial survey as a technique for estimating trends in manatee population size—problems and prospects. Pages 63–74 *in* T. J. O'Shea, B. B. Ackerman, and H. F. Percival, editors. Population biology of the Florida manatee. National Biological Service Information and Technology Report 1.

*Lefebvre, L. W., and R. K. Frohlich. 1986. Movements of radio-tagged manatees in southwest Florida, January 1985–March 1986. U.S. Fish and Wildlife Service, unpublished report. 87 pp.

Lefebvre, L. W., and H. I. Kochman. 1991. An evaluation of aerial survey replicate count methodology to determine trends in manatee abundance. Wildlife Society Bulletin 19:298–309.

Marmontel, M. 1993. Age determination and population biology of the Florida manatee, *Trichechus manatus latirostris*. Ph.D. dissertation, University of Florida, Gainesville. 408 pp.

Marsh, H. 1995. Fixed-width aerial transects for determining dugong population sizes and distribution patterns. Pages 56–62 *in* T. J. O'Shea, B. B. Ackerman, and H. F. Percival, editors. Population biology of the Florida manatee. National Biological Service Information and Technology Report 1.

Marsh, H., and D. F. Sinclair. 1989a. An experimental evaluation of dugong and sea turtle aerial survey techniques. Australian Wildlife Research 16:639–650.

Marsh, H., and D. F. Sinclair. 1989b. Correcting for visibility bias in strip transect aerial surveys of aquatic fauna. Journal of Wildlife Management 53:1017–1024.

*McGehee, M. A. 1982. Manatees (*Trichechus manatus*): abundance and distribution in and around several Florida power plant effluents during the winter of 1981–1982. Final report prepared for the Florida Power and Light Company, Contract 31534-86419. 67 pp.

Moore, J. C. 1951. The range of the Florida manatee. Quarterly Journal of the Florida Academy of Science 14:1–19.

*Odell, D. K. 1976. Distribution and abundance of marine mammals in South Florida: Preliminary results. Pages 203–212 *in* A. Thorhaug and A. Volker, editors. Biscayne Bay: past/present/future. Proceedings of a symposium, 2–3 April 1976. Special Report 5. University of Miami, Sea Grant Program.

Odell, D. K. 1979. Distribution and abundance of marine mammals in the waters of the Everglades National Park. Pages 673–678 *in* R. M. Linn, editor. Proceedings of the First Conference on Scientific Research in the National Parks, New Orleans, Louisiana, 9–12 November 1976. U.S. Department of the Interior, National Park Service, Transactions and Proceedings Series 5, Volume 1.

O'Shea, T. J. 1988. The past, present, and future of manatees in the southeastern United States: realities, misunderstandings, and enigmas. Pages 184–204 *in* R. R. Odom, K. A. Riddleberger, and J. C. Ozier, editors. Proceedings of the Third Southeastern Nongame and Endangered Wildlife Symposium, Georgia Department of Natural Resources, Social Circle.

O'Shea, T. J., C. A. Beck, R. K. Bonde, H. I. Kochman, and D. K. Odell. 1985. An analysis of manatee mortality patterns in Florida, 1976–81. Journal of Wildlife Management 49:1–11.

O'Shea, T. J., and W. C. Hartley. 1995. Reproduction and early-age survival of manatees at Blue Spring, St. Johns River, Florida. Pages 157–170 *in* T. J. O'Shea, B. B. Ackerman, and H. F. Percival, editors. Population biology of the Florida manatee. National Biological Service Information and Technology Report 1.

O'Shea, T. J., and H. I. Kochman. 1990. Florida manatees: Distribution, geographically referenced data sets, and ecological and behavioral aspects of habitat use. Pages 11–22 *in* J. E. Reynolds, III and K. Haddad, editors. Report of the workshop on geographic information systems as an aid to managing habitat for West Indian manatees in Florida and Georgia. Florida Marine Research Publications 49.

O'Shea, T. J., and C. A. Langtimm. 1995. Estimation of survival of adult Florida manatees in the Crystal River, at Blue Spring, and on the Atlantic Coast. Pages 194–222 *in* T. J. O'Shea, B. B. Ackerman, and H. F. Percival, editors. Population biology of the Florida manatee. National Biological Service Information and Technology Report 1.

*Packard, J. M. 1985. Development of manatee aerial survey techniques. Manatee Population Research Report 7, Technical Report 8-7. Florida Cooperative Fish and Wildlife Research Unit, University of Florida, Gainesville. 68 pp.

*Packard, J. M., R. K. Frohlich, J. E. Reynolds, III, and J. R. Wilcox. 1984. Factors influencing indices of manatee abundance of manatees in the Fort Myers region, winter 1983/84. Manatee Population Research Report 5, Technical Report 8-5. Florida Cooperative Fish and Wildlife Research Unit, University of Florida, Gainesville. 63 pp.

Packard, J. M., R. K. Frohlich, J. E. Reynolds, III, and J. R. Wilcox. 1989. Manatee response to interruption of a thermal effluent. Journal of Wildlife Management 53:692–700.

*Packard, J. M., and R. Mulholland. 1983. Analysis of manatee aerial surveys: a compilation and preliminary analysis of winter aerial surveys conducted in Florida between 1977 and 1982. Manatee Population Research Report 2, Technical Report 8-2. Florida Cooperative Fish and Wildlife Research Unit, University of Florida, Gainesville. 119 pp.

Packard, J. M., D. B. Siniff, and J. A. Cornell. 1986. Use of replicate counts to improve indices of trends in manatee abundance. Wildlife Society Bulletin 14:265–275.

Packard, J. M., R. C. Summers, and L. B. Barnes. 1985. Variation in visibility bias during aerial surveys of manatees. Journal of Wildlife Management 49:347–351.

Pollock, K. H., and W. L. Kendall. 1987. Visibility bias in aerial surveys: a review of estimation procedures. Journal of Wildlife Management 51:502–510.

*Powell, J. A. 1981. The manatee population in Crystal River, Citrus County, Florida. Pages 33–40 *in* *R. L. Brownell, Jr. and K. Ralls, editors. The West Indian manatee in Florida. Proceedings of a workshop held in Orlando, Fla., 27–29 March 1978. Florida Department of Natural Resources, Tallahassee. 154 pp.

Powell, J. A., and G. B. Rathbun. 1984. Distribution and abundance of manatees along the northern coast of the Gulf of Mexico. Northeast Gulf Science 7:1–28.

*Powell, J. A., and J. C. Waldron. 1981. The manatee population in Blue Spring, Volusia County, Florida. Pages 41–51 *in* *R. L. Brownell, Jr. and K. Ralls, editors. The West Indian manatee in Florida. Proceedings of a workshop held in Orlando, Fla., 27–29 March 1978. Florida Department of Natural Resources, Tallahassee. 154 pp.

Provancha, J. A., and M. J. Provancha. 1988. Long-term trends in abundance and distribution of manatees (*Trichechus manatus*) in the northern Banana River, Brevard County, Florida. Marine Mammal Science 4:323–338.

*Provancha, J. A., and M. J. Provancha. 1989. Summary of 1987 and 1988 manatee aerial surveys at Kennedy Space Center. National Aeronautical and Space Administration Technical Memorandum 102783. 17 pp.

Rathbun, G. B. 1988. Fixed-wing airplane versus helicopter surveys of manatees *Trichechus manatus*. Marine Mammal Science 4:71–75.

Rathbun, G. B., J. P. Reid, R. K. Bonde, and J. A. Powell. 1995. Reproduction in free-ranging Florida manatees. Pages 135–156 *in* T. J. O'Shea, B. B. Ackerman, and H. F. Percival, editors. Population biology of the Florida manatee. National Biological Service Information and Technology Report 1.

Rathbun, G. B., J. P. Reid, and G. Carowan. 1990. Distribution and movement patterns of manatees (*Trichechus manatus*) in northwestern peninsular Florida. Florida Marine Research Publications 48:1–33.

Ratnaswamy, M. J., and H. E. Winn. 1993. Photogrammetric estimates of allometry and calf production in fin whales, *Balaenoptera physalus*. Journal of Mammalogy 74:323–330.

*Raymond, P. W. 1981. Manatees (*Trichechus manatus*): abundance and distribution in and around several Florida power plant effluents during the winter of 1981–82. Final report prepared for the Florida Power and Light Company, Contract 31534-81511. 62 pp.

Reid, J. P., R. K. Bonde, and T. J. O'Shea. 1995. Reproduction and mortality of radio-tagged and recognizable manatees on the Atlantic coast of Florida. Pages 171–191 *in* T. J. O'Shea, B. B. Ackerman, and H. F. Percival, editors. Population biology of the Florida manatee. National Biological Service Information and Technology Report 1.

Reid, J. P., G. B. Rathbun, and J. R. Wilcox. 1991. Distribution patterns of individually identifiable West Indian manatees (*Trichechus manatus*) in Florida. Marine Mammal Science 7:180–190.

*Reynolds, J. E., III. 1993. Distribution and abundance of Florida manatees (*Trichechus manatus latirostris*) around selected power plants following winter cold fronts: 1992–1993. Report for Florida Power and Light Company, Order B91135-00073. 36 pp.

*Reynolds, J. E., III. 1994. Distribution and abundance of Florida manatees (*Trichechus manatus latirostris*) around selected power plants following winter cold fronts: 1993–1994. Report for Florida Power and Light Company, Order B91135-00139. 37 pp.

*Reynolds, J. E., III, B. B. Ackerman, I. E. Beeler, B. L. Weigle, and P. F. Houhoulis. 1991. Assessment and management of manatees (*Trichechus manatus*) in Tampa Bay. Pages 289–306 *in* S. F. Treat and P. A. Clark, editors. Proceedings of the Second Tampa Bay Area Scientific Information Symposium, 27 February–1 March 1991, Tampa, Fla.

*Reynolds, J. E., III, and C. J. Gluckman. 1988. Protection of the West Indian manatee in Florida. Document Number PB 88-222922, National Technical Information Service, Springfield, Va. 85 pp.

Reynolds, J. E., III, and J. R. Wilcox. 1985. Abundance of West Indian manatees (*Trichechus manatus*) around selected Florida power plants following winter cold fronts: 1982–1983. Bulletin of Marine Science 36:413–422.

Reynolds, J. E., III, and J. R. Wilcox. 1986. Distribution and abundance of the West Indian manatees (*Trichechus manatus*) around selected Florida power plants following winter cold fronts: 1984–1985. Biological Conservation 38:103–113.

Reynolds, J. E., III, and J. R. Wilcox. 1994. Observations of Florida manatees (*Trichechus manatus latirostris*) around selected power plants in winter. Marine Mammal Science 10:163–177.

*Rose, P. M., and S. P. McCutcheon. 1980. Manatees (*Trichechus manatus*) abundance and distribution in and around several Florida power plant effluents. Final report prepared for the Florida Power and Light Company, Contract 31534-86626 128 pp.

Samuel, M. D., E. O. Garton, M. W. Schlegel, and R. G. Carson. 1987. Visibility bias during aerial surveys of elk in northcentral Idaho. Journal of Wildlife Management 51:622–630.

Samuel, M. D., and K. H. Pollock. 1981. Correction of visibility bias in aerial surveys where animals occur in groups. Journal of Wildlife Management 45:993–997.

Shane, S. H. 1983. Abundance, distribution, and movements of manatees in Brevard County, Florida. Bulletin of Marine Science 33:1–9.

Sidle, J. G., and J. W. Ziewitz. 1990. Use of aerial videography in wildlife habitat studies. Wildlife Society Bulletin 18:56–62.

*Snow, R. W. 1992. The distribution and relative abundance of the Florida manatee in Everglades National Park. Interim report, March 1991 to February 1992. South Florida Research Center, Everglades National Park. Unnumbered.

Steinhorst, R. K., and M. D. Samuel. 1989. Sightability adjustment methods for aerial surveys of wildlife populations. Biometrics 45:415–425.

Taylor, B. L., and T. Gerrodette. 1993. The uses of statistical power in conservation biology: the vaquita and northern spotted owl. Conservation Biology 7:489–500.

Unsworth, J. W., L. Kuck, and E. O. Garton. 1990. Elk sightability model validation at the National Bison Range, Montana. Wildlife Society Bulletin 18:113–115.

*U.S. Fish and Wildlife Service. 1989. Florida manatee (*Trichechus manatus latirostris*) recovery plan. U.S. Fish and Wildlife Service, Atlanta, Ga. 98 pp.

*Valade, J. A. 1990. Coastal Georgia manatee assessment. Final report for Georgia Department of Natural Resources, Contract 462-511-960966. Unnumbered.

Weigle, B. L., and K. D. Haddad. 1990. Applications of the Florida Department of Natural Resources' Marine Resources Geographic Information System to manatee biology and management. Pages 23–27 *in* J. E. Reynolds, III and K. D. Haddad, editors. Report of the workshop on geographic information systems as an aid to managing habitat for West Indian manatees in Florida and Georgia. Florida Marine Research Publications 49:23–27.

*Weigle, B. L., J. E. Reynolds, III, G. W. Patton, and J. R. Wilcox. 1988. Manatee (*Trichechus manatus*) winter use of warm water discharges in Tampa Bay. Pages 153–164 *in* K. Mahadevan, R. K. Evans, P. Behrens, T. Biffar, and L. Olsen, editors. Proceedings Southeastern Workshop on Aquatic Ecological Effects of Power Generation, 3–5 December 1986, Sarasota, Fla. Mote Marine Lab. Report 124.

Woolf, H. B., editor. 1977. Webster's New Collegiate Dictionary. G. & C. Merriam Company, Springfield, Mass. 1,536 pp.

Zoodsma, B. J. 1991. Distribution and behavioral ecology of manatees in southern Georgia. M.S. thesis, University of Florida, Gainesville. 202 pp.