

# Arc Marine

*GIS for a Blue Planet*

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*Foreword by Jane Lubchenco*

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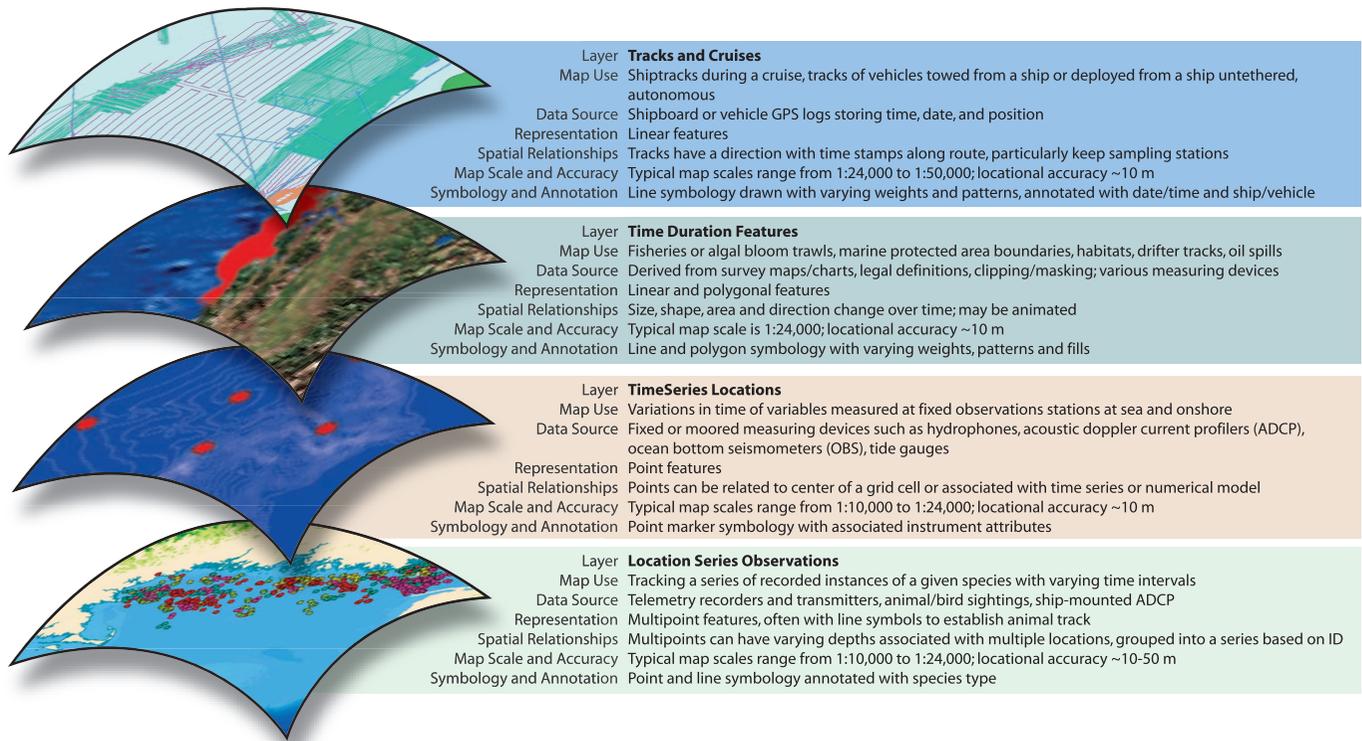


# 4

## chapter four

# Marine animal data applications

*This chapter describes how Arc Marine can be used to associate the movements of various species of marine animals (horizontally on the sea surface and vertically through the water column) with important environmental parameters such as sea surface temperature, chlorophyll a concentration, bathymetry, and coastal geology. Five case studies demonstrate the importance of this association by way of InstantaneousPoints, LocationSeriesPoints, TimeDurationLines, TimeDurationAreas, FeatureAreas, and rasters. The first case study examines the movements of humpback whales in the North Atlantic during summer, while the second examines the impact of the Stellwagen Bank National Marine Sanctuary on humpback whale abundance. The third study examines the migration of loggerhead sea turtles (tracked by satellite transmitters) and its association with surface chlorophyll a concentration off the coast of North Carolina and out into the western Atlantic. The fourth study analyzes the vertical dive profiles of loggerhead turtles in association with deeper chlorophyll a and bathymetry around the Cayman Islands. The final study examines the populations of harbor seals and the locations of where they leave the water (haul-out) onto rock ledges, as a function of time. These case studies rely on the use of the extensive data holdings in the Ocean Biogeographic Information System-Spatial Ecological Analysis of Megavertebrate Populations (OBIS-SEAMAP) and have significant implications, discussed later in this chapter, for marine animal conservation and management.*



## Introduction

Associating marine animal observations with environmental data is a common practice in conservation research. This approach enables researchers to describe and predict animal habitat based on environmental conditions. The Arc Marine data model framework easily facilitates the linking of environmental data spatially and temporally to other features. Animal observations are often collected concurrent with related data. When dealing with fishery or endangered species issues, it is often useful to relate these observations to permanent or ephemeral political boundaries (e.g., protected areas, temporary closures, oil spills). With the increased availability of remotely sensed data, more biologists and managers are correlating these data sources to animal observations that are coincident in space and time. This has provided an extremely diverse and useful data resource.

This chapter presents research from the Marine Geospatial Ecology Lab of the Nicholas School of the Environment and Earth Sciences at Duke University. Program researchers examined Arc Marine data types relevant to marine animal data applications using data provided through the OBIS-SEAMAP project (Halpin et al. 2006). OBIS-SEAMAP (<http://seamap.env.duke.edu/>) is an online archive of georeferenced data on marine mammals, seabirds, and sea turtles collected by scientific contributors globally via boat, plane, beach, and telemetry tags. Given the highly migratory nature of these taxa, the time and place of their observation is critical for associating the environmental conditions to describe habitat. Demonstrated below are the visualization and analytical advantages of using specific Arc Marine data types across five case studies: (1) cetacean surveys, (2) marine protected area, (3) sea turtle tagging, (4) sea turtle dive profiles, and (5) seal haul-outs (places where seals leave the water). See table 4.1 for a summary of the data types used per case study. Also important for the case studies are FeatureAreas, which may be used to represent static marine boundaries around marine protected areas (MPAs) or other kinds of restricted areas at sea (figures 4.1a and b).

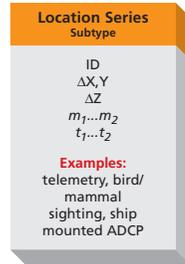
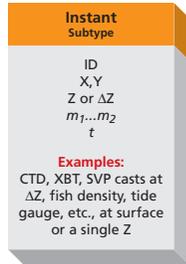
Case study	Arc Marine data types
1. Cetacean surveys	<ul style="list-style-type: none"> <li>• InstantaneousPoint: species observations</li> <li>• TimeDurationLines: ship track</li> </ul>
2. Marine protected area	<ul style="list-style-type: none"> <li>• TimeDurationAreas: marine protected area</li> </ul>
3. Sea turtle tagging	<ul style="list-style-type: none"> <li>• LocationSeriesPoint: individual animal locations</li> <li>• TimeDurationLines: animal track</li> </ul>
4. Sea turtle dive profiles	<ul style="list-style-type: none"> <li>• LocationSeriesPoint with z-value: individual animal locations at depth</li> </ul>
5. Seal haul-outs	<ul style="list-style-type: none"> <li>• TimeSeriesPoint: animal haul-out ledges</li> </ul>

Table 4.1 Arc Marine data types implemented by case study.

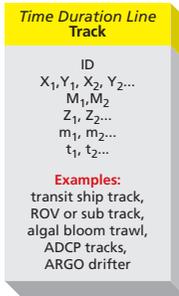
## Common Marine Data Types

### Marine Points

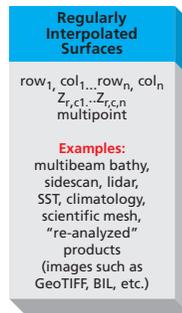
Instantaneous Points



### Marine Lines



### Marine Rasters/Grids/Meshes



a

Figure 4.1a and b Portions of the main Common Marine Data Types diagram (from chapter 2) representing the various combinations of marine data types as explained in the case studies below. Headings in italics are abstract feature classes in Arc Marine. All other headings are feature classes or subtypes of feature classes.

## A series of points

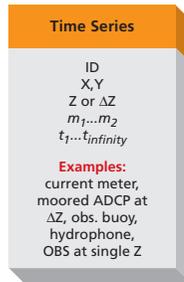
As initially described in the discussion of marine surveys in chapter 3, Arc Marine presents a hierarchical structure for organizing the various feature classes, with MarineFeature being atop the hierarchical structure from which three abstract subclasses, MarinePoint, MarineLine, and MarineArea, inherit. The use of feature classes from each of these is described below.

This chapter looks at another implementation of the InstantaneousPoint feature class, which inherits from the superclass MarinePoint. The LocationSeries subtype of the InstantaneousPoint feature class is designed for representing features where the x- and

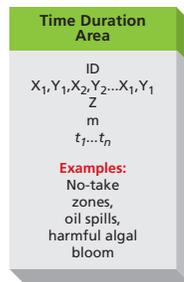
## Common Marine Data Types

### Marine Points

Time Series Point



### Marine Areas



b

y-coordinates of the feature changes for different time stamps. Specifically, it is meant to be applied to the tracking of marine animals, where the animal is the feature being tracked but obviously is not fixed at a single location. Rather, the movement of the animal is being recorded with the use of telemetry over a long duration of time, and each recording includes a new x- and y-coordinate—a new point feature and time stamp. The InstantaneousPoint feature class provides the attribute TimeValue for recording the time stamp of when the location is being recorded. It is the combination of TimeValue plus the x- and y-coordinates that denotes the unique feature. The ZValue attribute allows for the storage of a single depth, the sea surface, for example. The SurveyID attribute is a key field used in the relationship class SurveyInfoHasPoints to link the features of this feature class with

the SurveyInfo object class and in essence is a unique survey. The SeriesID is a key field provided to construct a relationship between the features of InstantaneousPoint with a row in the object class Series. The PointType attribute is the subtype attribute denoting the type of InstantaneousPoint. For the LocationSeries subtype, this value is set to 4.

One of the principal concepts introduced by the LocationSeries subtype is that many instances of the feature class represent the same object—marine animal, in this case. To track or group the multiple instances of a specific animal being added to the InstantaneousPoint feature class, a mechanism was required to support the identification of the points that were essentially the same animal or to thematically group like features. In Arc Marine, this mechanism is the Series object class. The case studies presented in this chapter note that researchers use this to track several sightings of an individual animal.

The Series object class is a simple table containing only the SeriesID attribute. This attribute is the key field for linking the Series object class to any other feature class that implements that attribute. Given that each new sighting is recorded with a new x- and y-coordinate and time stamp, through the SeriesID that unique animal can be identified, and all of its sightings can be mapped accordingly. Currently in Arc Marine, this includes the InstantaneousPoint and TimeDurationArea feature classes. Although a relationship class has not been added to Arc Marine, the structure for establishing a relationship is in place in that both classes have the SeriesID attribute. Users can easily extend the Series class to store the attributes necessary for grouping the features. Additionally, since the SeriesID attribute is included in the InstantaneousPoint feature class, Arc Marine does not limit the use of this to the LocationSeries subtypes.

## Tracks and cruises

This chapter also looks at the use of the TimeDurationLine feature class. TimeDurationLine is never instantiated in a geodatabase but rather is an abstract subclass of MarineLine. TimeDurationLine is designed for features where data values along the line would change over time. The TimeDurationLine feature class introduces four attributes in addition to the FeatureID and FeatureCode inherited from the MarineFeature superclass. The StartDate attribute denotes the time stamp for the beginning of the line, whereas the attribute EndDate denotes the time stamp for the end of the line. The next two attributes, VehicleID and CruiseID, are key fields for linking this feature class to their respective object classes.

The TimeDurationLine has one instantiatable subclass called Track, which was initially introduced in chapter 3. In the Track feature class, the properties HasZ and HasM have been implemented so that the linear feature could have varying depths (ZValues) along the line. Furthermore, the HasM property provides for the feature having a linear measurement system along the feature. In this case, the units of the linear measurement system would be based on time, and the StartDate and EndDate attributes inherited from TimeDurationLine define the extent of the measurement system. Consequently, locations along the line can be interpolated based on a time stamp between the time extent. Track

introduces several new attributes in addition to those inherited from the `TimeDurationLine` class. A complete description of those can be found in chapter 3.

An accompanying object class of the `Track` feature class is `Cruise`, which was also introduced in chapter 3. `Cruise` defines an expedition, which contains one or more instances of `Track` and is connected to `Track` through the `CruiseHasTracks` relationship class. The `CruiseHasTracks` relationship is a one-to-many and uses the `CruiseID` from the `Cruise` object class as the origin field and the `CruiseID` that `Track` inherits from `TimeDurationLine` as the destination field. The `Cruise` object class also delivers several additional fields for describing a given cruise.

## Area features

`MarineArea`, as with `MarineLine` and `MarinePoint`, also inherits from the superclass `MarineFeature`, acquiring the `FeatureID` and `FeatureCode` attributes. `MarineArea` is an abstract class for the purpose of organizing the area feature classes. Two subclasses to `MarineArea` delivered in Arc Marine can be instantiated: `FeatureArea` and `TimeDurationArea`.

`FeatureArea` is a simple polygon feature class for the purpose of adding feature classes that represent physical features that can be represented with polygonal geometry. `FeatureArea` adds no new attributes in addition to the `FeatureID` and `FeatureCode` inherited from `MarineArea`. `FeatureArea` is dealt with extensively in chapter 6.

The `TimeDurationArea` feature class is also a subclass of `MarineArea` that can be instantiated. This feature class is designed to hold polygonal features whose geometry changes over time. The concept behind `TimeDurationArea` is similar to the `LocationSeries` subtype of the `InstantaneousPoint` feature class. The concept involves a polygonal feature changing shape, requiring new geometry and new instances in the feature class at various time steps, while still representing the same feature. This is also similar to the ESRI coverage data structure implementation of regions, which allows for a thematic grouping of multiple polygons into a collection that can be referenced by a single attribute. Consequently, `TimeDurationArea` uses the `Series` table for collecting similar features through the use of the `SeriesID`. `TimeDurationArea` adds the attribute `SeriesID` as a key field for relating to the `Series` object class, along with `StartDate` (the beginning time stamp for a given feature) and `EndDate` (the ending time stamp for a given feature). Some applications may require one or both of the date fields.

A simple example to illustrate the use of the `TimeDurationArea` feature class along with the `Series` table is the example of an oil spill. A polygon represents the boundary of the oil spill and denotes the feature at a given point in time. The boundary has a specific geometry, and the `StartDate` is populated with a time stamp (not all applications will use the `StartDate` and the `EndDate`). At a point in time in the future, the geometry denoting the boundary of the oil spill will change, the time stamp will be recorded, and a new record or feature will be added to the `TimeDurationArea` feature class. This process is repeated multiple times in the future, with each instance receiving new polygonal geometry and a time stamp. The mechanism for identifying the polygons as being from the same oil spill is

the Series table (figure 4.1a and b). Each of the instances added to TimeDurationArea also receive the same value for the SeriesID attribute. The Series table serves as a lookup table, defining the attributes of the feature that the many polygons represent.

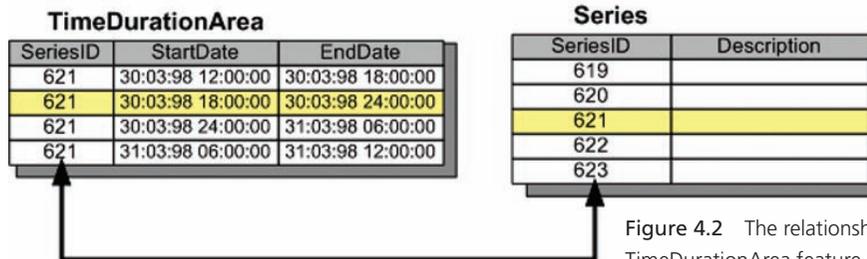


Figure 4.2 The relationship between the TimeDurationArea feature class and the Series object class.

## Featured case studies

### Cetacean surveys

**Introduction:** This case study correlated environmental data with observations of marine mammals during boat and aerial surveys. The relationship between animals and their environment provides critical knowledge to inform key conservation issues such as assessment of potential anthropogenic impacts and improved marine protected area design (Hooker et al. 1999; Hyrenbach et al. 2000). In particular, the study found sea surface temperature (SST) a useful variable in defining the limits of a species range (Mikol 1997) and in delineating marine protected area boundaries (Hyrenbach et al. 2000). More specifically, this case study investigated observations of humpback whales (*Megaptera novaeangliae*) in the North Atlantic during summer to identify the range of SSTs where the mammals are found. The humpback whale migrates to feeding grounds in high-latitude waters in summer (Mackintosh 1965). Predicting species habitat is complicated and beyond the scope of this book. However, the general environmental envelope of the species (Walker and Cocks 1991) can be quantified simply.

**Data:** The National Oceanic and Atmospheric Administration Northeast Fisheries Science Center (NOAA NEFSC) conducted 13 shipboard and aerial surveys from 1991 to 2002 in U.S. waters in the northern Atlantic. The surveys have been archived at OBIS-SEAMAP (figure 4.3). The surveys primarily wanted to estimate abundance of cetacean species. The NEFSC datasets contain 6,477 cetacean observations from 1991 to 2002, including 188 humpback whale sightings. Each set of the sightings for a specific month and year is synchronized with the remotely sensed SST image for that month and year. The values from the SST data layer are then sampled at each of the sighting locations. This process is repeated across all months and years. Maximum and minimum temperature values define the thermal envelope for humpback whales in the northeast Atlantic.

Each dataset produces cetacean sighting data along with locations of the ships/aircraft. Cetacean sightings are point events with location and time. They also include identification of species sighted and number observed. In OBIS-SEAMAP, species are coded with

1 - 13 out of 13 datasets found

Datasets are grouped by source organization in alphabetic order.  
Click provider name to expand/hide datasets of the provider.  
Collapse all

dataset name	map	platform	effort	begin	end	years	birds	mammals	turtles
NOAA Northeast Fisheries Science Center (NEFSC)									
NEFSC 1992 aj9201		boat	yes	1992	1992			1238	1
NEFSC 1995 AJ9501 (Part I)		boat	yes	1995	1995			150	
NEFSC 1995 AJ9501 (Part II)		boat	yes	1995	1995			1401	
NEFSC 1995 pe9501		boat	yes	1995	1995			433	7
NEFSC 1999 aj9902		boat	yes	1999	1999			1021	5
NEFSC Aerial Survey - Experimental 2002		plane	yes	2002	2002			332	7
NEFSC Aerial Survey - Summer 1995		plane	yes	1995	1995			304	71
NEFSC Aerial Survey - Summer 1998		plane	yes	1998	1998			422	282
NEFSC Harbor Porpoise Survey 1991		boat	yes	1991	1991			770	1
NEFSC Survey 1991		boat	yes	1991	1991			80	
NEFSC Survey 1997		boat	yes	1997	1997			60	
NEFSC Survey 1998 1		boat	yes	1998	1998			492	13
NEFSC Survey 1998 2		boat	yes	1998	1998			309	6

**Figure 4.3** Thirteen datasets from NOAA Northeast Fisheries Science Center are registered in OBIS-SEAMAP (<http://seamap.env.duke.edu/datasets>). The datasets are downloadable in comma-separated values (CSV) format and ESRI shapefiles.

Courtesy of National Marine Fisheries Services.

the taxonomic serial number from the Integrated Taxonomic Information System (<http://www.itis.usda.gov/>). The ship and aircraft locations are used to construct track lines. Sea surface temperatures along the ship/aircraft tracks are picked up and summarized to determine if the survey areas—more specifically the linear locations where the ships/aircraft traveled—affected the environmental envelope. All the NEFSC datasets provide survey effort data, which sums up to 1,626.8 effort hours.

Loading data into Arc Marine: Datasets of observations and effort were downloaded from the OBIS-SEAMAP site (<http://seamap.env.duke.edu/datasets>) in shapefile format. The general information of the NEFSC ship and aerial surveys were stored in an Arc Marine Cruise table. OBIS-SEAMAP distinguishes individual surveys by unique dataset identification numbers, which were used to populate the CruiseID field in the Cruise table. CruiseID became the key to relate the dataset and its observations as well as its ship/aircraft tracks.

The InstantaneousPoint feature class (figure 4.4) represented sighting locations. Researchers loaded the features in the shapefiles into InstantaneousPoint. They recorded dates and times of the sightings in the TimeValue field in InstantaneousPoint.

In Arc Marine, all attributes other than time and location are managed in separate tables. These attributes differ from the simpler data attributes attached to point observations in the shapefiles downloaded from OBIS-SEAMAP. The MarineEvent feature class can be used as an attribute table for InstantaneousPoint. Animal observations from ship/aerial surveys are, however, structurally different from data that MarineEvent was intended to hold. While MarineEvent can hold a single value (in the DataValue field), animal sightings typically include many parameters, such as species identification, animal count, sea state, and others. A survey can also record multiple values for one parameter. For example, it may record animal counts (parameter) based on three different observers or estimated values (e.g., low, high, and best estimate).

Although users can modify the MarineEvent table to better fit animal sightings data, the researchers chose to create a new table. Thus, they created and loaded the Animal-Sightings table with the attributes from the shapefiles. It contains CruiseID, taxonomic serial

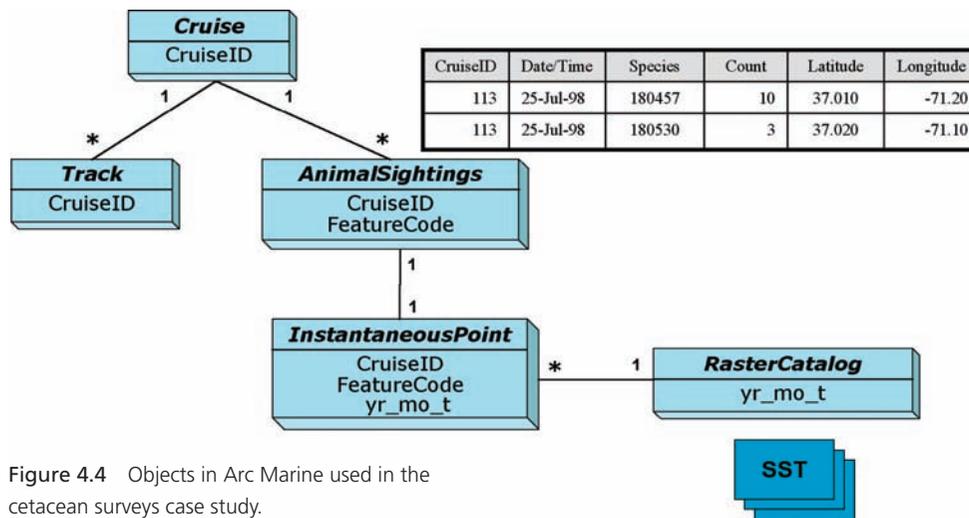


Figure 4.4 Objects in Arc Marine used in the cetacean surveys case study.

numbers of species sighted, animal counts, and unique ID that distinguishes sightings from multiple datasets. Researchers defined relationship classes to link *AnimalSightings* to *InstantaneousPoint*.

Intuitively, ship and aircraft tracks were stored as a *Track* feature class. Datasets provided by OBIS-SEAMAP are accompanied by polyline shapefiles of the track when available. A Relationship Class was created to link *Track* to *Cruise* with *CruiseID* as a key. Environmental data such as SST is available in various formats from a variety of providers. Fortunately, for well-recognized data such as NOAA/NASA Pathfinder Advanced Very High Resolution Radiometer (AVHRR) Sea Surface Temperature ([podaac-www.jpl.nasa.gov/sst/](http://podaac-www.jpl.nasa.gov/sst/)), converters from the original data format to ESRI GRID format are usually available. Once converted to ESRI GRID format, the creation of a raster catalog provided a convenient way to store these datasets in Arc Marine. A raster catalog can be related to objects in a geodatabase, allowing users to select one of the raster layers based on currently selected vector features. For example, a relationship class would allow users to select an SST layer in the catalog corresponding to point sightings in a specific month and year.

This case study used monthly sea surface temperature images that were compiled in a raster catalog. To create a relationship in general, it is advisable to add a new field that has key values pointing to the raster catalog and the related object (*AnimalSightings* in this case). In this study, a field holding year and month (e.g., 2001/07) was added to match sightings with monthly SST layers. The relationship class allows users to select an SST layer in the catalog that corresponds to sightings in a specific month and year.

Loading raster images into the raster catalog was straightforward because the layers already existed as ESRI rasters. After loading all the layers into the raster catalog, researchers populated the newly added relationship field with appropriate values. They did this by adding the raster catalog to an ArcMap document and using the Calculate Values function on the field in the attribute table (figure 4.5). They saved the calculation formula for future use.

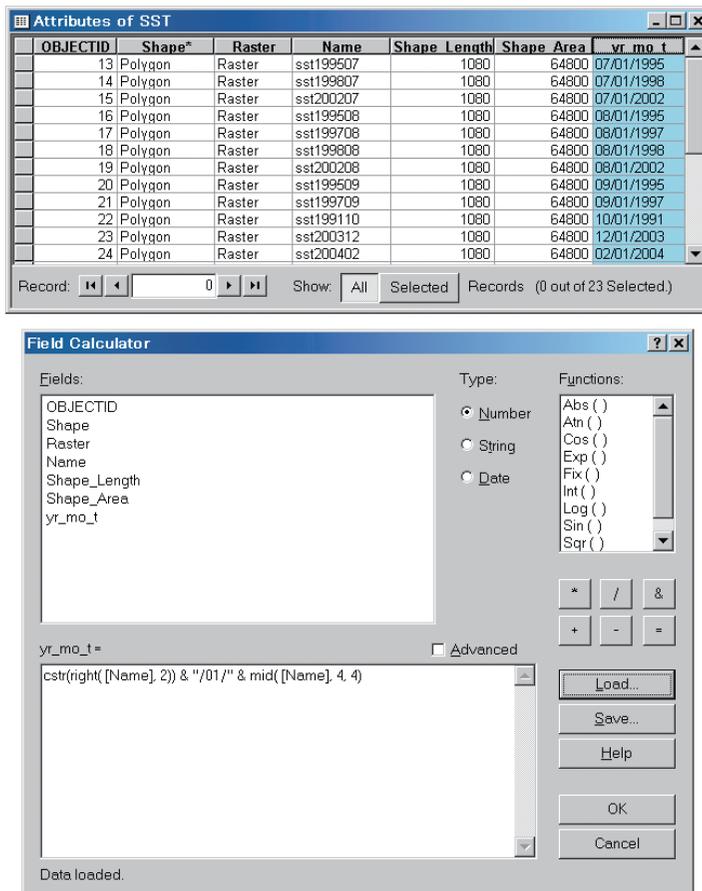


Figure 4.5 Fields can be added to the raster catalog using the Field Calculator as a convenient way to fill in the values. This example shows the added field “yr\_mo\_t,” a key relating SST to InstantaneousPoint.

Analysis with Arc Marine: The NEFSC datasets contain sightings of species (figure 4.6). Thus, the first step of the study was to extract humpback whale sightings. Researchers did this by using Select by Attribute on the AnimalSightings table with the humpback whale’s ITIS number (180530) as a criterion. The result was saved as a layer for future use.

A specific month and year was selected from the humpback whale layer (e.g., July 1998). The corresponding SST layer in the catalog was selected by following the relationship class from InstantaneousPoint (in this case, the humpback whale layer) to the SST raster catalog. As spatial analysis tools cannot operate directly on a raster layer in the raster catalog, the layer itself needed to be added to an ArcMap document. Users can do this by specifying the raster name in the following manner: CatalogName\Raster.OBJECTID=xx, where CatalogName is the name of the raster catalog and xx is the ObjectID of the raster layer. The humpback whale and the SST layers were then entered as inputs to the Sample tool to extract SST values where sightings in a specific month and year occurred. Researchers

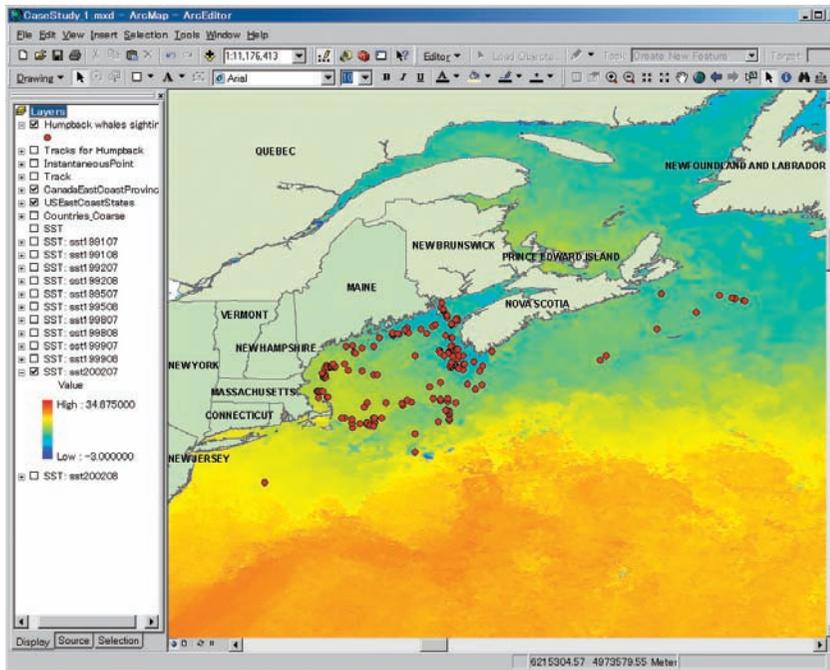


Figure 4.6 Researchers recorded 188 sightings of humpback whales in the NEFSC datasets from 1991 to 2002. The humpback whale sightings were first selected from the AnimalSightings table (not shown on the map) using Select by Attribute, then the selection was linked to InstantaneousPoint via a relationship class.

Courtesy of National Marine Fisheries Services.

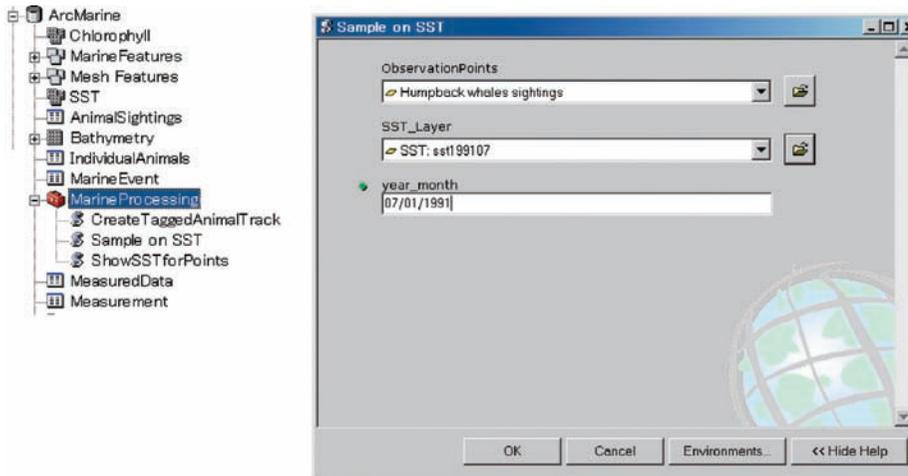


Figure 4.7 ArcToolBox can contain user-defined geoprocessing toolboxes where useful scripts can be added. The script named “Sample on SST” automates filtering of humpback whale sightings by a specified year and month and passes the selection to the Sample tool to obtain the SST in the specified year and month.

saved the results in a table, which contains sighting locations (latitude and longitude) and corresponding sea surface temperature values.

As the procedure described above needed to be repeated for all combinations of month and year, researchers developed a geoprocessing script with the Python scripting language to streamline the procedure (figure 4.7). To make the best use of Arc Marine, a toolbox was created and the script was added as a tool in the toolbox. After repeating the procedure for all combinations of month and year, researchers combined the resulting tables and used the R statistical package to summarize the data.

Researchers sampled sightings and SST along the ship/aircraft surveys in the same way. Starting from the humpback whale layer, which is a subset of the InstantaneousPoint, they used relationship classes to identify the cruises in which humpback whales were sighted. Cruise table has a relationship to Track, so it was straightforward to select ship/aircraft tracks for the cruises selected (figure 4.8). The selected tracklines were buffered with an arbitrarily determined strip width of 1 km. For each combination of year and month, the tracklines were further filtered with the year and month and overlaid on the corresponding SST layer. The Zonal Statistics as Table tool was used to calculate statistics of the SST layer where it was traversed by the buffered trackline polygon.

Results: Humpback whales were observed during the summer months of July and August in 1991, 1992, 1995, 1998, 1999, and 2002. Latitudes of observations ranged from 39.7 to 44.9 degrees north. Excluding exceptional values in August 1992 and July 1995, the mean sea surface temperature ranged from 11.8°C to 16.8°C (table 4.2 and figure 4.9). The SST along the ship/aircraft tracklines ranged from 2.8°C to 27.7°C. A closer look reveals that the humpback whale was never sighted where the water temperature was above 23.2°C

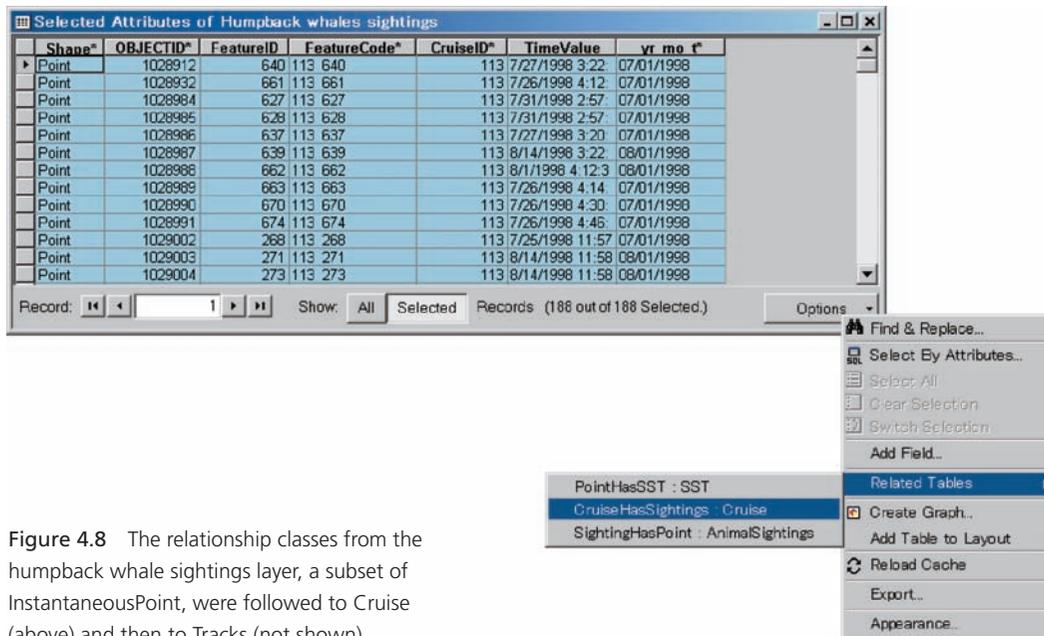


Figure 4.8 The relationship classes from the humpback whale sightings layer, a subset of InstantaneousPoint, were followed to Cruise (above) and then to Tracks (not shown).

		'91/07	'91/08	'92/07	'92/08	'95/07	'95/08	'98/07	'98/08	'99/07	'99/08	'02/07	'02/08
Whales	Mean	12.07	13.84	11.77	10.42	23.17	15.12	16.84	16.51	13.84	14.44	15.70	15.67
	Standard error	0.19	0.62	0.00	1.70	0.00	0.68	0.30	0.70	0.86	0.29	0.62	0.00
	Minimum	11.85	10.87	11.77	7.50	23.17	9.67	13.20	10.42	12.97	10.95	8.10	15.67
	Maximum	12.45	16.05	11.77	14.85	23.17	19.35	18.82	19.95	14.70	18.97	18.67	15.67
	Count	3	7	1	5	1	27	29	16	2	36	15	2
	Confidence level (95.0%)	0.81	1.51	N/A	4.73	N/A	1.41	0.61	1.48	10.99	0.59	1.32	0.00
Tracks	Mean	11.61	13.40	11.89	13.86	24.28	17.76	19.11	16.38	14.15	14.63	18.07	15.07
	Standard error	0.17	0.14	0.27	0.12	0.12	0.12	0.12	0.15	0.31	0.12	0.11	0.20
	Minimum	8.17	-3	9	6.59	18.89	4.57	-3	2.84	12.97	5.77	-3	10.72
	Maximum	16.12	19.27	14.32	17.25	27.67	26.32	25.57	21.75	17.10	18.97	23.62	22.64
	Count	113	277	19	253	255	1183	722	350	15	260	452	111

Table 4.2 Monthly (July and August) summary of sea surface temperature (°C) where humpback whales were sighted and ships/aircraft traveled.

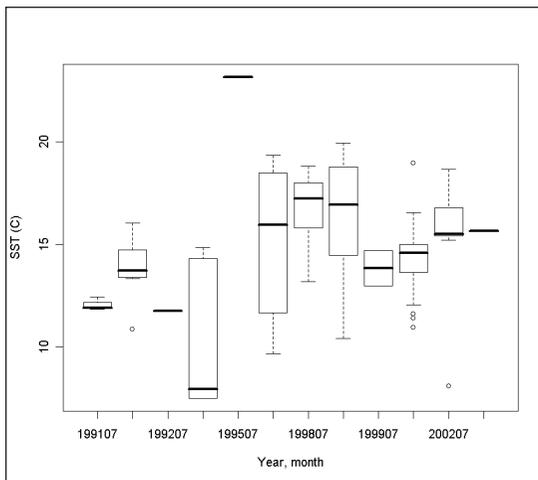


Figure 4.9 Statistical box plot showing monthly SST (°C) where whales were sighted.

(the highest temperature where the whale was sighted is 23.17°C). However, according to a t-test, the mean SST for the sightings was not statistically different from the tracklines, suggesting the environmental envelope found in this study (11.8–16.8°C) was restricted by the areas surveyed.

Discussion: Humpback whales were observed during summer months where water temperatures ranged from 11.8°C to 16.8°C. However, researchers could not conclude that whales do not range in waters beyond this temperature range. Broader areas should be surveyed to answer this question. Humpback whales were never sighted in surface

temperature above 23.2°C, whereas the survey tracklines covered waters with surface temperatures up to 27°C. More detailed statistics may suggest that the upper limit of the environmental envelope is about 23°C in summer feeding grounds. The environmental envelope is defined with various variables. For example, the water depth can be associated with feeding behavior (Sardi et al. 2005). This can be examined by using bathymetry data in place of the SST layers in this case study. Prey such as krill, while more difficult to detect, tends to be a strong predictor of habitat (Bryant et al. 1981).

To make analytical processes simple and focus the reader's attention on Arc Marine, this case study used "raw" SST images, which can contain inaccurate values due to cloud cover. For example, three of the year-and-month combinations reported -3°C as a minimum water temperature for tracklines, which should have been eliminated before the analysis. For more accurate analyses, appropriate quality control procedures should be taken.

### Marine protected area

**Introduction:** This example is similar to the cetacean survey case study with the addition of the `TimeDurationArea` feature class, representing a dynamic marine sanctuary boundary. The study aimed to examine the impact of a marine sanctuary on cetacean abundance. This kind of study can be used to evaluate marine protected areas.

**Data:** The case study focuses on Stellwagen Bank National Marine Sanctuary. The sanctuary, covering more than 800 square miles in Massachusetts Bay, was established in 1992 (<http://stellwagen.noaa.gov/>). Endangered right whales, humpback whales, and many other cetaceans frequent the sanctuary, making it one of the top 10 whale-watching sites in the world, according to World Wildlife Fund (Hoyt 1991). Researchers obtained the sanctuary boundary as a polygon shapefile from the NOAA National Marine Sanctuaries Web site (<http://sanctuaries.noaa.gov/>).

Researchers first extracted from the shapefile the cetacean sightings and ship/aerial survey tracks that occurred within the boundaries of the sanctuary. The sightings and tracks were further divided into those that occurred before and after the designation of the sanctuary. Next, researchers calculated the total number of sightings and observation effort hours before and after the sanctuary was designated. Comparison of sighting counts per hour before and after the sanctuary establishment gives a rough estimate of the effectiveness of the sanctuary in marine mammal abundance.

**Loading data into Arc Marine:** Loading of the NEFSC marine mammals observations into Arc Marine is described in the first case study with cetacean surveys. Since this second case study focuses on the species abundance before and after the sanctuary establishment, the sanctuary is considered to be an object that turns on and off over time (it is initially off and then turns on once the sanctuary is designated). This type of feature can be stored as a `TimeDurationArea` (figure 4.10).

It is good practice to create a new feature class for each time-area closure because of the potential for thematically different time sensitive features (e.g., sanctuaries and fishery closures function differently and will have different attributes). Researchers created a new `MarineSanctuaries` feature class for this case study and inherited properties from

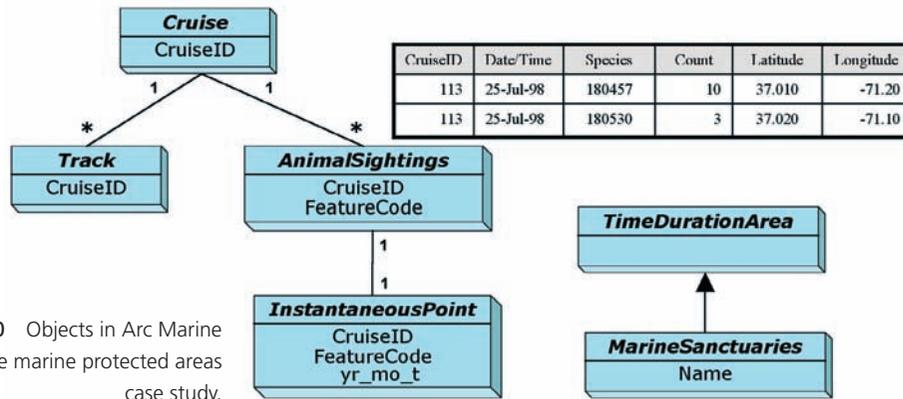


Figure 4.10 Objects in Arc Marine used in the marine protected areas case study.

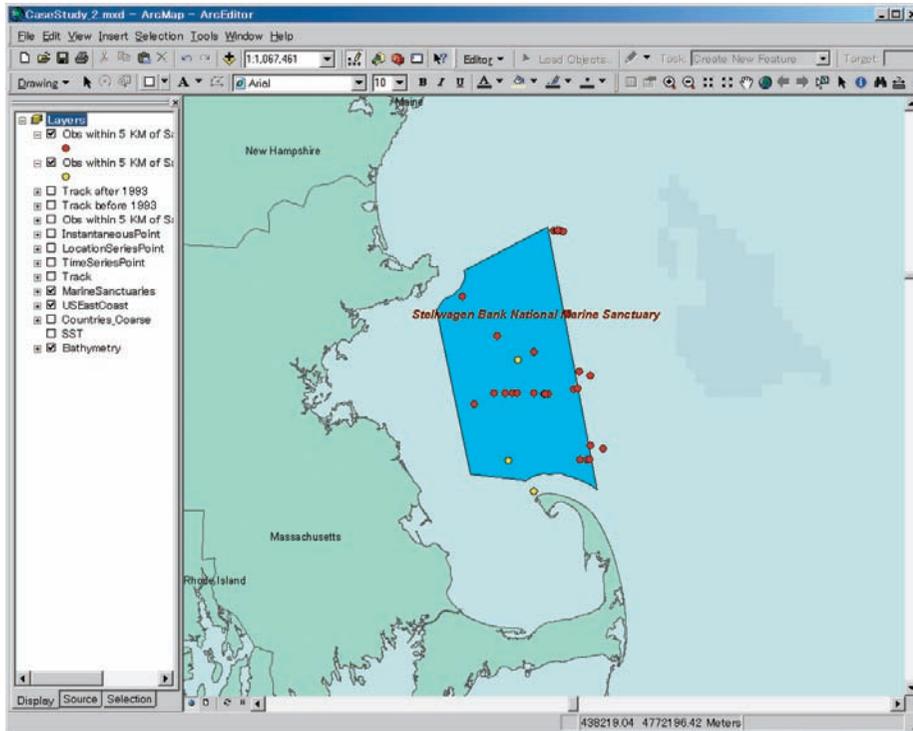


Figure 4.11 Spatial query allows the user to filter the sighting points that fall in the sanctuary boundary (blue polygon). Case study 2 arbitrarily designated a 5-km buffer, assuming animals in the buffer would occur in the sanctuary. The filtered sightings were split into those dated either before (yellow dots) or after (red dots) the sanctuary was established. The results were saved as separate layers.

Courtesy of National Marine Fisheries Services.

TimeDurationArea, with a new field added to hold sanctuary names. Only one polygon was loaded in to the class representing the boundary of Stellwagen Bank National Marine Sanctuary, though it could contain the boundaries of more than one sanctuary.

Analysis with Arc Marine: The NEFSC datasets contained observations encompassing much of the U.S. North Atlantic. Researchers first extracted the sightings that fell in the boundary of the sanctuary (figure 4.11). This was done by spatial query on MarineSanctuaries and InstantaneousPoint. The resulting selection was split into those dated before and after the establishment of the sanctuary. The two selections were saved as separate layers. The observation datasets associated with the selected points (species and count) were found using a relationship class, which extracted related rows from AnimalSightings. This process was repeated for observation points before and after the sanctuary establishment. The resulting sighting datasets were exported to a file in CSV format for later calculation.

To calculate sighting rates, ship/aircraft tracklines were imported as a Track feature class and related to the AnimalSightings table via the Cruise table (see first case study). Observations were matched with AnimalSightings and the appropriate cruises and tracklines were identified, following the relationship class. Since this process brought up all the tracks for the cruises, they needed to be constrained to those that passed the sanctuary boundary (figure 4.12). This query was similar to the process used to select InstantaneousPoint data falling within the sanctuary. Next, the effort hours were determined by calculating the difference between StartDate and EndDate in Track. Observation counts were the number of rows in the selection by species. Observation rates were obtained by dividing the counts by hours of effort.

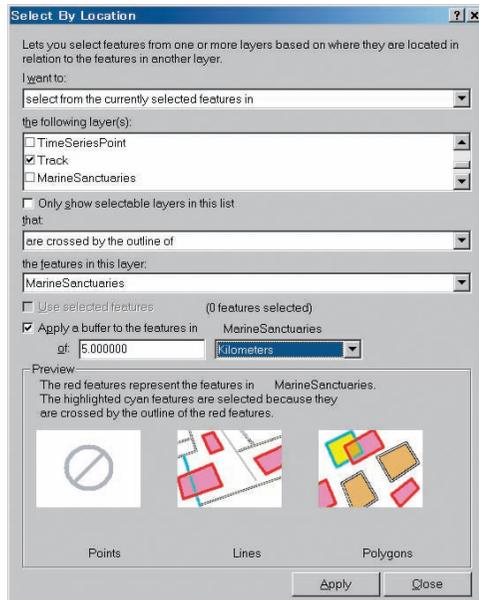


Figure 4.12 After following the relationship classes from AnimalSightings to Cruise to Track, a spatial query extracted the tracks passing over the sanctuary boundary.

Before				After			
Species	Sightings		Sighting/hour	Species	Sightings		Sighting/hour
Fin whale	1	1	0.5128	Fin whale	1	1	0.2474
Humpback whale	1	1	0.5128	Fin/Sei whale	1	1	0.2474
Unidentified large whale	1	1	0.5128	Humpback whale	12	22	2.9693
<b>All cetacean</b>	3	3	1.5384	Minke whale	2	3	0.4949
				Unidentified large whale	2	2	0.4949
				White-sided dolphin	4	86	0.9898
				<b>All cetacean</b>	22	115	5.4437

Table 4.3 Sighting rates of cetaceans before and after the establishment of the sanctuary.

Results: Overall, 1.95 hours of effort were reported before designation of the sanctuary in 1992, with three whale species sighted during that time, yielding an observation rate of 1.5 per hour (table 4.3). A total of 4.04 hours of effort were reported after the establishment of the sanctuary with 22 cetacean species observed for a rate of 5.4 observations per hour. In particular, the endangered humpback whale (*Megaptera novaeangliae*) exhibited a much higher observation rate after the sanctuary was established. By contrast, the observation rate for the fin whale (*Balaenoptera physalus*), another endangered species in this area, exhibited no increase.

Discussion: Due to the deficiency of the sightings before the establishment of the sanctuary, the direct comparison of the sighting rates before and after the event is not statistically relevant. Only 1.95 effort hours occurred before the event, and those are concentrated in October, when migratory species such as humpback whales may have left the area for wintering areas to the south. On the other hand, the sightings after the event were recorded during summer surveys (July and August), when the humpback whale is likely to be more abundant, with two exceptions sighted in early September.

Prey productivity affects humpback whale abundance, which was reported to have increased dramatically during 1992–93 in the northern Gulf of Maine. Fewer whales were found nearshore, but larger herring stocks were found offshore (Blaylock et al. 1995). Further analysis should help to explain these anomalous events.

## Sea turtle tagging

Introduction: Researchers from the Duke University Marine Laboratory, in cooperation with the NOAA Southeast Fisheries Science Center (SEFSC), are studying interactions between sea turtles and commercial fisheries in North Carolina by tracking sea turtles using satellite transmitters (Read et al. 2004). Transmitter data is archived at OBIS-SEAMAP (<http://seamap.env.duke.edu/datasets/detail/316>), including location data for 6 green (*Chelonia mydas*) and 19 loggerhead (*Caretta caretta*) sea turtles from October 2003 to May 2006.

Loggerhead turtles migrate long distances between their natal beaches and oceanic habitats. However, their behaviors and habitats used in pelagic regions are not well known (Polovina et al. 2004). It is generally believed that juveniles forage mainly in the open ocean, while large adults forage in coastal waters, with a few exceptions (Hawkes et al. 2006). This case study examines the migration of two satellite tagged loggerhead turtles and their relation to remotely sensed chlorophyll *a* concentration. Chlorophyll *a* is a potential indicator of loggerhead prey abundance (Polovina et al. 2004).

**Data:** Of 19 loggerhead turtles whose locations were recorded in the Duke University Marine Laboratory dataset, two were selected for the study, one of which mainly stayed in the coastal region off North Carolina, while the other migrated into pelagic waters. Chlorophyll *a* concentration datasets used in the study were obtained from the Sea-viewing Wide Field-of-view Sensor (SeaWiFS, NASA Goddard Space Flight Center). The turtle locations were grouped on a monthly basis and each group overlain with the chlorophyll *a* concentration image for that month. The concentration values underlying the turtle locations were sampled and summarized.

**Loading data into Arc Marine:** Each tagged animal had a number of associated characteristics such as nickname, species, age, size, and gender. This information was stored in a Series table, a template with just two fields defined: OBJECTID and SeriesID. For this case study, researchers created a new table named IndividualAnimals, inheriting from the Series table the generic fields, plus the additional fields of nickname, species, age, size, gender, and taxonomic serial number. LocationSeriesPoint was used for the location data from the tagged animals (figure 4.13). Monthly chlorophyll *a* concentration datasets from SeaWiFS were stored in a raster catalog. See the first case study for more details about the raster catalog and how to load grids.

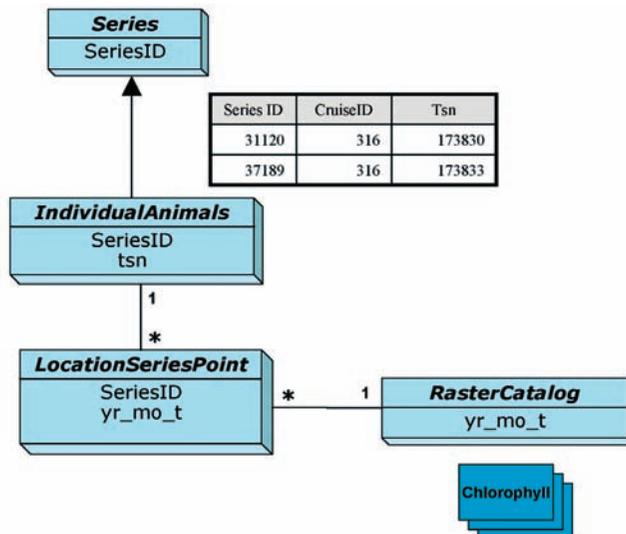
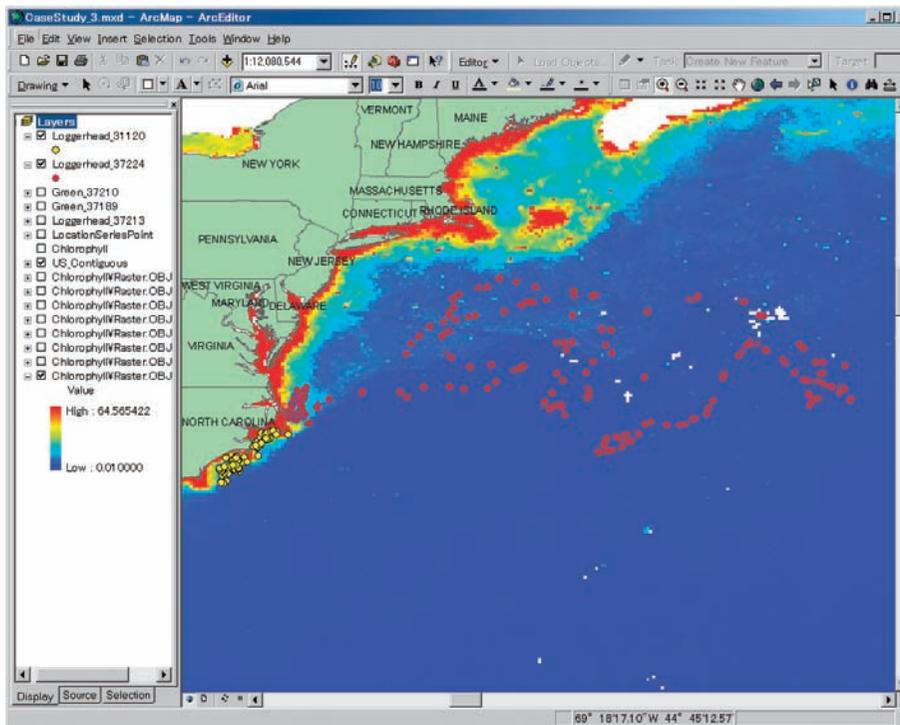


Figure 4.13 Objects in Arc Marine used in the sea turtle tagging case study.

Analysis with Arc Marine: The two study animals were selected from the IndividualAnimals table and linked to all corresponding location data in LocationSeriesPoint using the relationship class. The resulting locations were saved as a layer for later use for each individual animal. Monthly chlorophyll *a* concentration images were added to an ArcMap document for all corresponding month and year combinations for each individual turtle. The location data and chlorophyll image were entered as inputs to the Zonal Statistics as Table tool to summarize the chlorophyll *a* concentration values coincident with each location. This process was repeated for all combinations of year and month for both turtles. The results were combined in a spreadsheet in order to compare and contrast data related to coastal and oceanic movements.

Results: The loggerhead turtle that migrated to pelagic waters traveled more than 1,500 km away from its release location near the Outer Banks, North Carolina. It started its journey in October 2003 and reached the furthest point in April 2005 (figure 4.14). It returned to coastal waters in May 2005. As the turtle migrated from the coastal region to pelagic waters, the mean chlorophyll *a* concentration decreased from 0.94 mg/m<sup>3</sup> in October to 0.21 mg/m<sup>3</sup> in February.



**Figure 4.14** Basemap of the sea turtle tagging case study showing the movements of two loggerheads, one of which migrated to oceanic regions (red dots) and the other staying in coastal regions (yellow dots). Chlorophyll *a* concentration image for October 2003 is shown as an underlayer.

Data courtesy of Catherine McClellan, Duke University Marine Lab.

Day	Deepest Dive	Bathymetry	Chlorophyll
2004/06/23	26	-3,388.50	0.09
2004/06/24	30	-4,644.00	0.09
2004/06/25	72	-4,763.66	0.08
2004/06/26	72	-5,452.50	0.09
2004/06/27	36	-5,395.25	0.11
2004/06/28	44	-2,526.00	0.07
2004/06/29	52	-2,365.00	0.1
2004/06/30	72	-2,980.00	0.1
2004/07/01	88	-3,499.71	0.07
2004/07/02	104	-2,009.66	0.07
2004/07/03	30	-1.00	
2004/07/05	10	-1.00	0.06
2004/07/06	10		
2004/07/07	10	-82.00	0.07
2004/07/08	10	-201.00	
2004/07/09	10	2.50	0.07
2004/07/10	10	-37.66	0.06
2004/07/11	5	4.00	0.04
2004/07/12	26	-1,214.00	0.09
2004/07/14	30	-2,968.50	0.06
2004/07/15	52	-2,899.66	0.05
2004/07/16	30	-2,627.66	0.06
2004/07/17	60	-2,878.50	0.08

**Table 4.4** Summary of chlorophyll *a* concentrations on a monthly basis for the two loggerhead turtles. P-values of t-test between mean concentrations for oceanic and coastal loggerheads are also shown.

The loggerhead using only coastal waters remained within 80 km of the coastline near the Outer Banks during fall and traveled south during the winter. The sampled chlorophyll concentrations spanned a relatively small range from 0.47 to 0.66 mg/m<sup>3</sup> (table 4.4), with the higher mean chlorophyll *a* concentrations occurring during October and November 2003. Monthly mean chlorophyll *a* concentration was significantly different between coastal and pelagic loggerhead locations from winter to spring (p-values: 0.001, 0.012, 0.043, and 0.020 from December to April, respectively).

Discussion: The chlorophyll *a* concentration in the Mid-Atlantic Bight (MAB) has a clear annual cycle with higher concentration in winter and lower concentration in summer (Yoder et al. 2001). Although the coastal loggerhead in this study stayed south of MAB, assuming that the trend of chlorophyll *a* concentration in MAB is applied to the water off Outer Banks, it is speculated that the animal left the region when the concentration lowered in spring to a place with higher concentration. However, an additional examination indicated that the concentration off the Outer Banks in spring and in the area where the

animal stayed in spring were not different enough to prove this speculation ( $0.72 \text{ mg/m}^3$  in south of Outer Banks and  $0.70 \text{ mg/m}^3$  off Outer Banks in February 2004).

The oceanic loggerhead foraged under lower chlorophyll *a* concentration than the coastal loggerhead. This observation is not inconsistent with the life history characteristics of the loggerhead whereby young loggerheads mainly eat prey floating on sea surface (Polovina et al. 2004; Hawkes et al. 2006). SST provides another variable potentially influencing turtle movements (Polovina et al. 2004). The association of turtle movements with SST can be analyzed with Arc Marine in a similar manner to this case study (see also the first case study in this chapter).

### Sea turtle dive profiles

**Introduction:** This case study examined dive profile data obtained from a loggerhead sea turtle outfitted with a data-relay satellite transmitter. Attention is focused on the association between the dive profile and surrounding environmental data, including bathymetry and chlorophyll *a* concentration.

When Christopher Columbus discovered the Cayman Islands in 1503, the sea turtle population was estimated at more than 6.5 million turtles, and turtle fishing (“turtling”) came to form the basis of the economy and culture of the Cayman Islands. By the beginning of the nineteenth century, however, commercial exploitation had driven the sea turtle nesting population in the Cayman Islands to the brink of extinction. Turtles do still come to the islands to nest (Aiken et al. 2001), and waters around the islands serve as important feeding grounds for green (*Chelonia mydas*) and hawksbill (*Eretmochelys imbricata*) sea turtles.

Several conservation efforts have been put into effect recently on the islands. For example, with the help of schools and the local community, the Cayman Islands Department of Environment and the Marine Turtle Research Group (<http://www.seaturtle.org/mtrg/>) have begun a satellite telemetry project to track sea turtles. It is vital to understand the ecology of sea turtles for better conservation management. Many studies have been conducted regarding migration, feeding, and diving of sea turtles worldwide (Whiting and Miller 1998; Polovina et al. 2004; Hawkes et al. 2006).

**Data:** The telemetry data of sea turtles foraging around the Cayman Islands is registered in and downloadable from OBIS-SEAMAP (<http://seamap.env.duke.edu/datasets/detail/350>). Of the five sea turtles returned from the query (loggerhead and green sea turtles), a loggerhead for which a complete dive profile was available was chosen for the study. Dive profile data is not, however, publicly available from OBIS-SEAMAP at this time. Turtle locations obtained from the satellite transmitter were mapped and the dive profile (depth) was used to visualize movements in three-dimensional (3D) space in the ArcGlobe application in ArcGIS 3D Analyst.

Two environmental datasets were compared to the dive profile data. Monthly chlorophyll *a* concentration datasets used in the study were obtained from SeaWiFS. Bathymetry datasets were obtained from the 2-minute Gridded Global Relief Data (ETOPO2; U.S. Department of Commerce, NOAA, National Geophysical Data Center, 2001). These environmental

datasets were sampled at turtle locations and their values summarized by date. The dive profile was also used to calculate daily maximum dive depth. Depth was compared with summarized environmental data to find any potential relationships.

Loading data into Arc Marine: Locations from the tagged loggerhead were loaded into `LocationSeriesPoint` as described in the previous case study. The only difference was that a new field, `ZValue`, was added to `LocationSeriesPoint` to hold the dive depth. Bathymetry and monthly chlorophyll *a* concentrations for June and July 2004 were added to Arc Marine as rasters (figure 4.15).

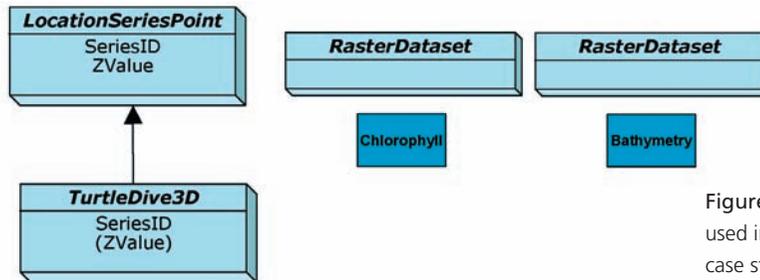
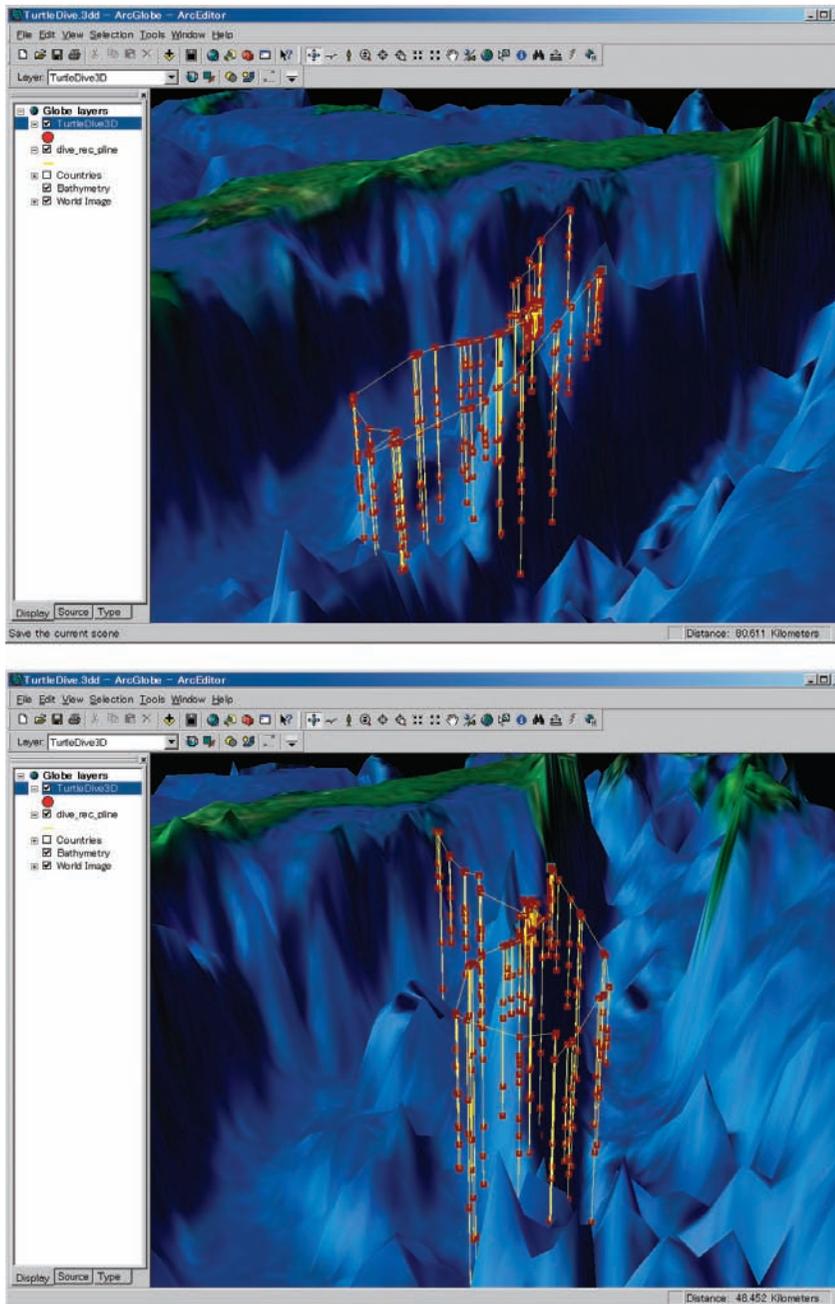


Figure 4.15 Objects in Arc Marine used in the sea turtle dive profile case study.

Although not essential to the analysis, visualization of the turtle dive in a 3D space offers excellent visual context for researchers and target audiences. For this purpose, researchers used ESRI ArcGlobe, which can take bathymetry data as an input to display the track, with the dive profile in perspective view (figure 4.16). There are two ways to visualize turtle dive data in three dimensions. A simple way is to use the `ZValue` field in `LocationSeriesPoint` as bathymetry data. In the Show Properties dialog box for the shapefile in ArcGlobe, go to the Elevation tab, check “Use constant value or expression”, and select the `ZValue` field from the combination box below it. Alternatively, `LocationSeriesPoint` can be converted to a 3D feature class with the Features to 3D tool available in the 3D Analyst toolbar. In this case, ArcGlobe is able to recognize a 3D feature class and automatically render it as a 3D feature. This case study took the latter approach.

Analysis with Arc Marine: The telemetry data from the tagged loggerhead was available from June 23, 2004, to July 17, 2004 (figure 4.17). The Zonal Statistics as Table tool was used to sample environmental values of the pixels under each turtle location for each environmental data layer, including one bathymetry layer and two monthly chlorophyll *a* layers (June and July 2004). The tool returned minimum, maximum, and mean data values by month. The maximum dive depth by date was calculated from the `ZValue` field. The results were combined in a tabular format for graphical display.

Results: The loggerhead in this study was tagged on June 28, 2004, and traveled approximately 90 km southeast of Grand Cayman, before turning around and heading back to Grand Cayman Island in a large, interesting loop (figure 4.18). The turtle returned to nest on Grand Cayman on July 3 and spent 10 days near the island before heading



**Figure 4.16** Visualization of the turtle dive in 3D ArcGlobe space. LocationSeriesPoints were converted to a 3D feature class, and ETOPO2 grids were used for bathymetry and elevation.

Courtesy of Brendan J. Godley Marine Turtle Research Group, Centre for Ecology and Conservation, University of Exeter in Cornwall, United Kingdom

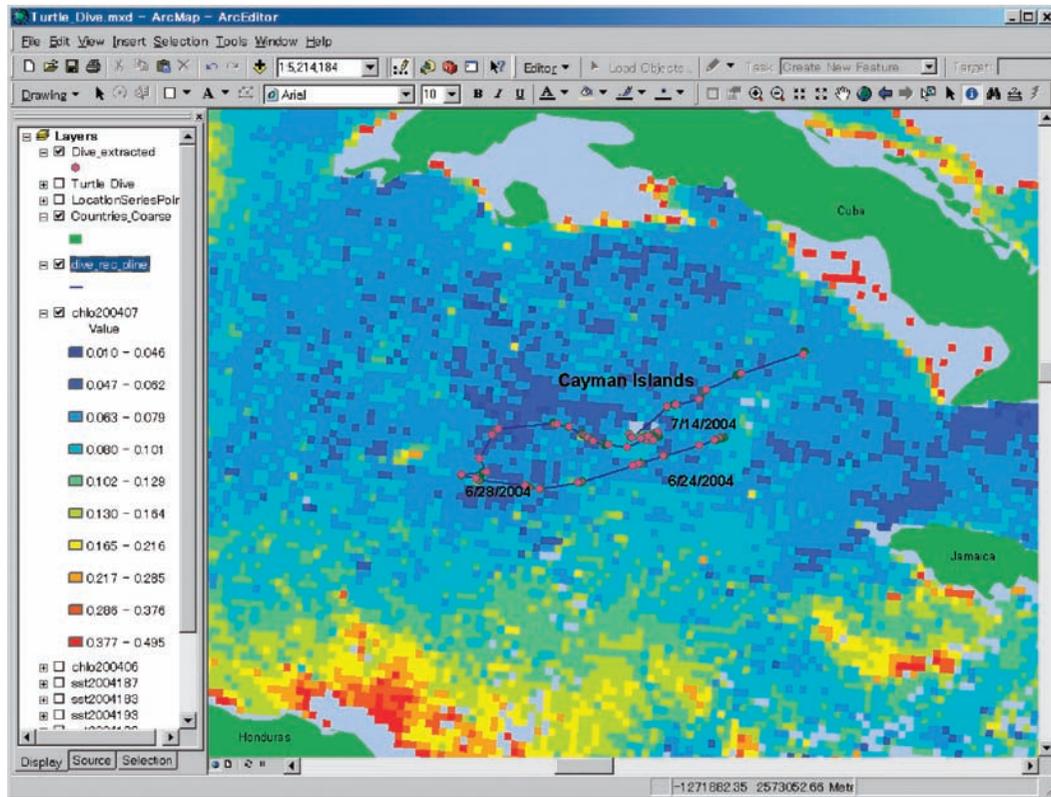


Figure 4.17 Route of a loggerhead turtle overlain on a grid of monthly chlorophyll a concentration for July 2004.

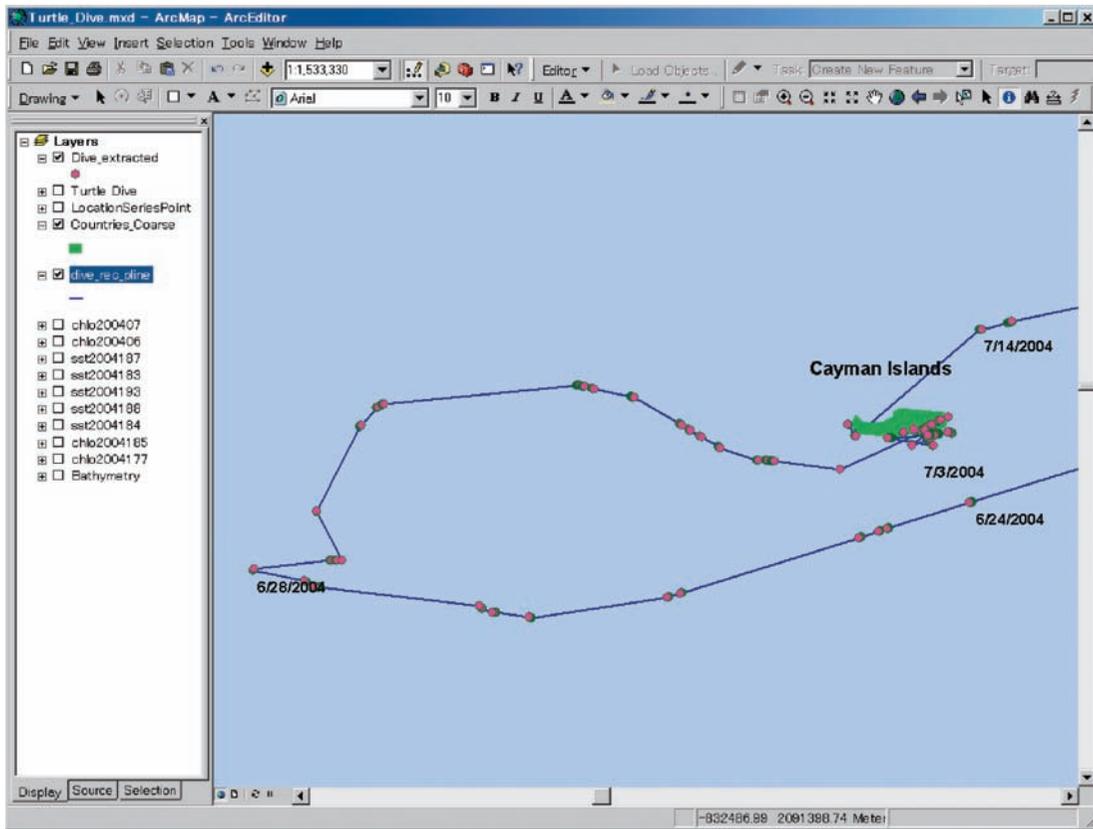


Figure 4.18 Closer view of loggerhead turtle movement in blue (with dive points in red) and Grand Cayman Island shown in green.

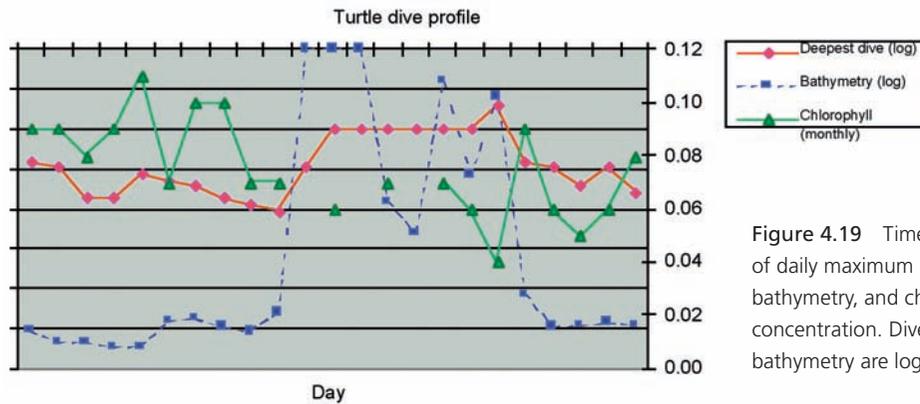
Courtesy of ESRI Data & Maps, 2005.

eastward. The maximum daily dive depth ranged from 5 meters to 104 meters (table 4.5 and figure 4.19). These results are consistent with those reported for loggerheads in the Pacific, which spend most of their time near the surface, at depths less than 100 m (Polovina et al. 2004). The turtle remained in shallow waters when near Grand Cayman, exhibiting deeper dives in pelagic waters. Since detailed statistical analyses are beyond the scope of the book, no clear tendency among turtle dive depth and chlorophyll *a* concentration was observed. However, it might be speculated that the loggerhead dived deeper as chlorophyll *a* concentration became lower as slight synchronization between them could be seen (figure 4.19).

Discussion: One may speculate that loggerheads dive deeper to seek prey where chlorophyll *a* concentrations are lower. This study did not find clear association between the turtle dive depth and the chlorophyll *a* concentration. However, the monthly chlorophyll *a* imagery is probably not an appropriate temporal scale to test this hypothesis. Finer temporal resolution data (e.g., 8-day) unfortunately had too many cloud-covered data gaps to be usable here.

Day	Deepest Dive	Bathymetry	Chlorophyll
2004/06/23	26	-3,388.50	0.09
2004/06/24	30	-4,644.00	0.09
2004/06/25	72	-4,763.66	0.08
2004/06/26	72	-5,452.50	0.09
2004/06/27	36	-5,395.25	0.11
2004/06/28	44	-2,526.00	0.07
2004/06/29	52	-2,365.00	0.1
2004/06/30	72	-2,980.00	0.1
2004/07/01	88	-3,499.71	0.07
2004/07/02	104	-2,009.66	0.07
2004/07/03	30	-1.00	
2004/07/05	10	-1.00	0.06
2004/07/06	10		
2004/07/07	10	-82.00	0.07
2004/07/08	10	-201.00	
2004/07/09	10	2.50	0.07
2004/07/10	10	-37.66	0.06
2004/07/11	5	4.00	0.04
2004/07/12	26	-1,214.00	0.09
2004/07/14	30	-2,968.50	0.06
2004/07/15	52	-2,899.66	0.05
2004/07/16	30	-2,627.66	0.06
2004/07/17	60	-2,878.50	0.08

**Table 4.5** Daily maximum dive depth (m) and the corresponding bathymetry (m) and chlorophyll *a* concentration (mg/m<sup>3</sup>). Blank cells indicate no data available.



**Figure 4.19** Time series trend of daily maximum dive depth, bathymetry, and chlorophyll *a* concentration. Dive depth and bathymetry are log-scaled.

While the loggerheads stayed in shallow waters around the island, they may have been foraging for benthic invertebrates, which are a dominant prey for loggerheads (Plotkin et al. 1993). On the other hand, the seafloor was far deeper than the turtle could dive when it traveled away from the island. Thus, it is thought that the loggerhead fed on prey other than benthic invertebrates. The currents and eddies may play an important role in gathering floating organisms as prey for sea turtles in their pelagic stage (Mortimer and Carr 1987). Sea surface current data may therefore be considered for future analysis with Arc Marine.

## Seal haul-outs

**Introduction:** This case study examined the abundance of adult harbor seals over time. Such a time series analysis is essential to understanding long-term population dynamics of seals in the area (Thompson et al. 2005). Seal populations in the northwest Atlantic are thriving, yet relatively few resources are available for seal research projects in the region. The east coast of the United States lacks a management plan for seals, primarily because managers do not have information on the spatial distribution of the species, and more specifically, where haul-out sites are located (Dow 2005).

**Data:** To address this management issue, aerial surveys were conducted from 1981 to 2001 to collect seal and pup counts along the coastline of Maine (Gilbert et al. 2005). The archived data collected is downloadable from OBIS-SEAMAP (<http://seamap.env.duke.edu/datasets/detail/315>). Gray seals (*Halichoerus grypus*) and harbor seals (*Phoca vitulina*) haul out on islands and rock ledges in the area. Aerial surveys were used in the survey area to count the number of seals on ledges each day by species. To provide a sampling unit to estimate the seal abundance, researchers arbitrarily grouped ledges into regions based on proximity. Final abundance values are summed by region.

**Loading data into Arc Marine:** Ledges were represented in the Arc Marine data model by nonmobile points where data accumulates over time. Each ledge was given a numeric identification code. Each region, comprising a group of ledges in close proximity to one another, was identified by a five-letter code. Regional boundaries were not explicitly defined. A convex hull polygon encompassing all the ledges in a region was created to visualize each. A region code linked a region and its member ledges. The time series of the seal counts were presented in tabular format, with each row providing date, species, and life stage from one survey. Time series data was linked to ledges using "LedgeID."

Ledges were represented in Arc Marine by the TimeSeriesPoint feature class. Point features for the ledges were created as a shapefile from latitude and longitude values from the survey dataset. The FeatureArea feature class was used to hold the region polygons (figure 4.20). Before loading the ledge points and region polygons into the appropriate feature classes in the geodatabase, a common field must be present or created to link them. In this case, the region code was the key and was stored in the FeatureCode field. There was no need to customize the TimeSeriesPoint and FeatureArea feature classes for this case study.

After loading the features into the feature classes, a relationship class was created to relate TimeSeriesPoint to FeatureArea. Since a region contained many ledges, the cardinality of the relationship was one to many (1:M). In order to calculate abundance trends by species and life stage, two fields were created for these attributes in the seal count

TimeSeries. TimeSeries was related to TimeSeriesPoint with FeatureID as a key, which stored ledge IDs.

Analysis with Arc Marine: With the relationship classes properly defined, seal counts were selected for a specific region (figure 4.21) by selecting a region of interest, opening the

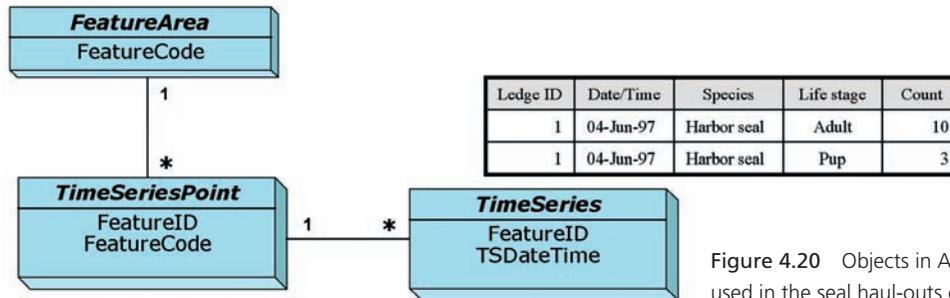


Figure 4.20 Objects in Arc Marine used in the seal haul-outs case study.

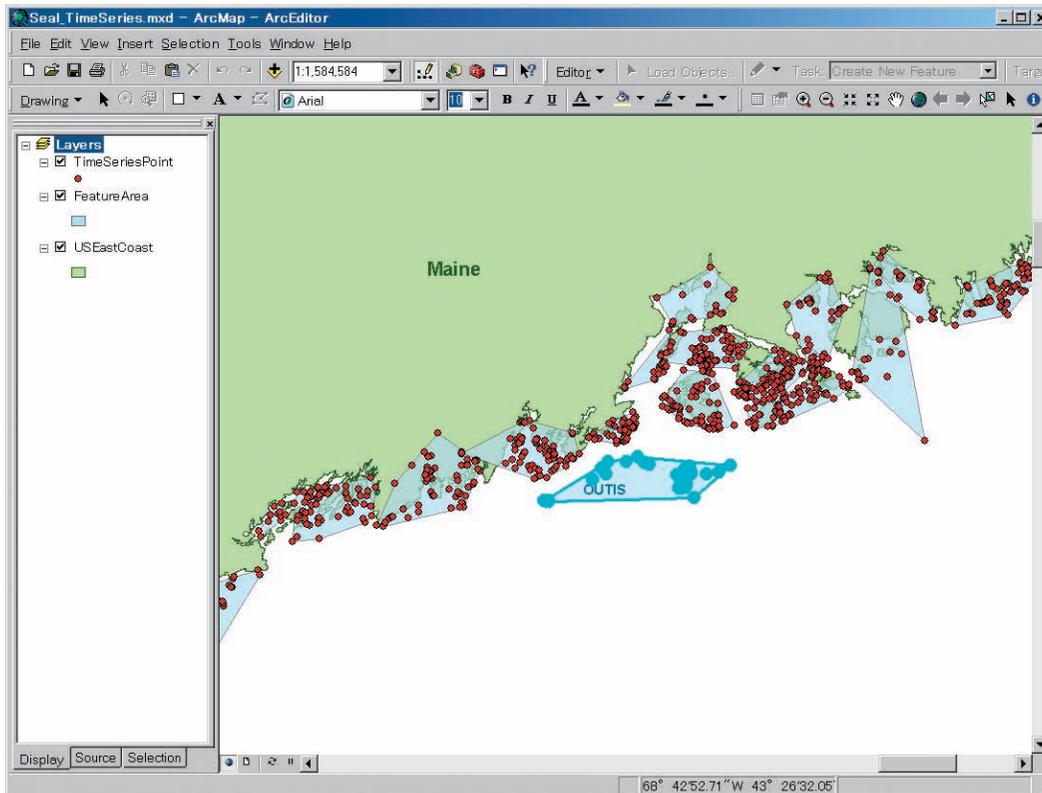


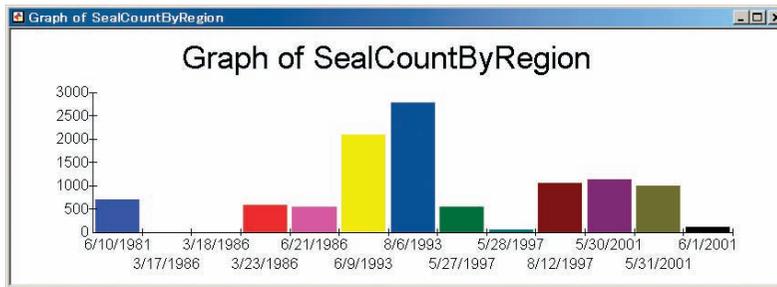
Figure 4.21 Harbor seal time series data for a specific region (e.g., OUTIS as shown above) may be extracted by way of relationship classes.

Data courtesy of James Gilbert.

attribute table and selecting Options>Related Tables. The appropriate relationship class was selected from the ledges attribute table and again for TimeSeries.

At this point, the selected seal counts mixed the two seal species and two life stages. To separate each species (e.g., harbor seal) and life stage (adult), Select by Attribute was performed on TimeSeries, with “Select from current selection” selected from Method. The adult harbor seal abundance trend was calculated from the resulting selection of TimeSeries. This was accomplished by right-clicking any field in the attribute table and selecting Summarize... . The summary statistics were saved as a table and stored in the geodatabase.

A graph of the summary statistics was created via Tools>Graphs>Create... (figure 4.22). The graph definition, including references to the summary statistics table, was saved in the ArcMap document. In general, it is a good practice to store the table in the geodatabase and overwrite it every time Summarize... is conducted. In this way, the graph definition is reusable for other regions, saving several steps in the graph creation wizard.



**Figure 4.22** Sample graph of abundance trend for adult harbor seals in a region (region code: OUTIS). The selection in TimeSeries is summarized by TSDateTime, and the result is saved as SealCountByRegion in Arc Marine.

Results and discussion: Six regions were compared, with all but one (BHBIH) displaying a similar trend (figure 4.23). Counts from the survey in May–June, 1993, to that in May–June, 2001, were similar for the five regions, while the BHBIH region exhibited an inverse trend. Since the BHBIH lies near the BHBMR and BHBSI regions and the other three (BOSHB, CASB, and CELPT) are also close together, this difference is likely not attributable to geographical location alone. Thompson et al. (1997) suggested that sea counts during the pupping season provide the best estimates of abundance, as it represents a time when a large part of the population aggregates. Looking only at surveys during the pupping season (May–June; Dow 2005), all regions display a similar trend, suggesting that the harbor seal population has increased over time.

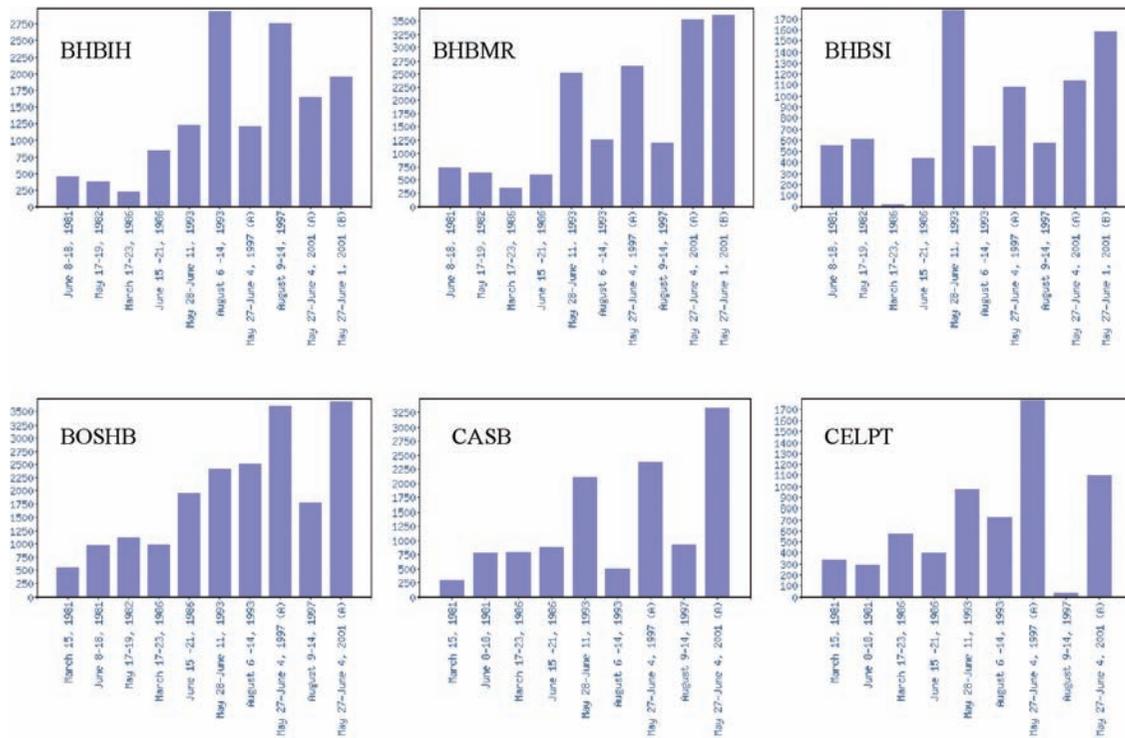


Figure 4.23 Time series of adult harbor seal counts in six regions. The upper three regions are close to each other geographically, as are the lower three.

## Conclusion

The case studies in this chapter demonstrate that the Arc Marine data model lets users directly establish spatial and temporal relationships to analyze marine animals within a dynamic ocean environment. These case studies depict the use of `InstantaneousPoints`, `LocationSeries Points`, `TimeDurationLines`, `TimeDurationAreas`, `FeatureAreas`, and raster data within the Arc Marine structure. While each of the case studies highlights different issues, the central theme that ties these applications together is the use of temporal and spatial relationships to link marine animal observations to their environmental context. This linkage in space and time is essential for scientific analysis and management of critical ocean species.

## Arc Marine class definitions featured in this chapter

FEATURE CLASSES	<b>InstantaneousPoint</b> —A point feature class representing features that are single observations in time and space. The x- and y-coordinates, plus a time stamp create the unique feature. An InstantaneousPoint can have multiple ZValues by implementing a relationship to the Measurement object class.		
	<b>Subtype</b>	LocationSeries	
	<b>Notes</b>	InstantaneousPoint is a subclass of the superclass MeasurementPoint.	
	<b>Properties</b>	None	
	<b>Fields</b>	FeatureID	A geodatabase-wide unique identifier and key field for participating in relationships
		FeatureCode	A user-defined code used for identifying a feature
		CruiseID	A key field for relating this feature class to a Cruise
		TimeValue	The time stamp for a given point
		ZValue	A single depth value for the point
		SurveyID	A foreign key to the SurveyInfo object class
		SeriesID	A foreign key to the Series object class
		PointType	Defines the subtype to be one of the following: 1 = Instant (default value) 2 = Sounding 3 = Survey 4 = LocationSeries
	<b>Track</b> —A linear feature class representing the path and event associated with going on a specific tangent from the expedition.		
	<b>Subtype</b>	None apply	
	<b>Properties</b>	HasM = True HasZ = True	
	<b>Notes</b>	Track is a subclass of TimeDurationLine. The TimeDurationLine is designed as a feature where the beginning of the line starts at a given time stamp and the end of the line has a different time stamp. A Track can also have a relationship with the Cruise object class via the CruiseID field. The relationship, CruiseHasTracks, is characterized by a Cruise and can have zero or many Tracks.	
	<b>Fields</b>	FeatureID	A geodatabase-wide unique identifier and key field for participating in relationships
		FeatureCode	A user-defined code used for identifying a feature
		StartDate	The beginning time stamp for the feature
		EndDate	The ending time stamp for the feature
VehicleID		A key field for relating this feature to the Vehicle	
CruiseID		A key field for relating this feature to the Cruise	
TrackID		An identifier for a Track feature	
Name		The name of a specific Track	
Method		Text describing the method for a specific Track	
Description		Text describing the Track	
LocalDesc	Text describing the locale of the Track		

FEATURE CLASSES (cont'd)	<b>TimeDurationArea</b> —A class representing area features that have a beginning time stamp and an ending time stamp.		
	<b>Subtype</b>	None apply	
	<b>Properties</b>	HasM = True HasZ = True	
	<b>Notes</b>	The TimeDurationArea is a feature class representing area features that have varying x,y,z locations and a beginning and ending time stamp.	
	<b>Fields</b>	FeatureID	A geodatabase-wide unique identifier and key field for participating in relationships
		FeatureCode	A user-defined code used for identifying a feature
		SeriesID	A foreign key to the Series object class
StartDate		The beginning time stamp for the feature	
EndDate		The ending time stamp for the feature	
OBJECT CLASSES	<b>SurveyInfo</b> —Designed for storing information about a specific survey.		
	<b>Notes</b>		
	<b>Fields</b>	SurveyID	A key field for relating this table to a feature class
		StartDate	The beginning date of the survey
		EndDate	The ending date of the survey
		Description	A general description of the survey
		DeviceID	A key field for relating a survey with a Measuring device
		TrackID	A key field for relating a survey with a Track
	<b>Series</b> —Designed for storing information about a group of features that could be collected into a series.		
	<b>Notes</b>		
	<b>Fields</b>	SeriesID	A key field for relating this table to a feature class
	<b>Cruise</b> —Defines the characteristics of a ship for the duration of an expedition.		
	<b>Notes</b>		
	<b>Fields</b>	CruiseID	An identifier for a given cruise
		Code	A user-defined code for a given cruise
		Name	The name of the cruise
		Purpose	The purpose of the cruise
Status		Defines the status of the cruise	
Description		A general description of the cruise	
StartDate		The beginning time stamp for the cruise	
EndDate		The ending time stamp for the cruise	
ShipName	The name of the ship participating in the cruise		

OBJECT CLASSES (cont'd)	<b>MeasuredData</b> —Used for storing recorded values for a given parameter.		
	<b>Notes</b>		
	<b>Fields</b>	MeasurementID	A key field for relating this table to the Measurement table
		ParameterID	A key field for relating this table to the Parameter table
		DeviceID	A key field for relating this table to the MeasuringDevice Table
		DataValue	The recorded value
	<b>MeasuringDevice</b> —Used for storing information pertaining to the device taking the measurements.		
	<b>Notes</b>		
	<b>Fields</b>	DeviceID	A key field for relating this table to either another table or feature class
		Name	The name of the measuring device
		Description	A description of the measuring device
		VehicleID	A key field relating this table to the Vehicles table
	<b>Parameter</b> —Stores some basic information about the parameters being measured.		
	<b>Notes</b>	This table can be used in a couple of different ways. It can be used as a mechanism for querying a geodatabase for a specific parameter and then finding values of a particular type in related tables. Alternatively, it can be used as a lookup table of parameter types for a particular value.	
	<b>Fields</b>	ParameterID	The unique identifier of a specific parameter
Name		The name of a parameter	
Description		The description of a parameter	
Quantity		The quantity type for a parameter. This is solved by the use of a coded value domain: 1 = Scalar, 2 = Vector	
Unit		The unit of measure for a parameter	
Significant Digits		The number of significant digits defining this parameter	

RELATIONSHIPS	<b>SurveyInfoHasPoints</b>	1 : *	One Survey can have zero or many points
	<b>CruiseHasTracks</b>	1 : *	One Cruise can have zero or many Tracks

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#### Case study content

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