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ABSTRACT OF THE DISCLOSURE

A method is provided to predict the biological consequences to marine animals from exposure to multiple underwater impulsive sources by simulating underwater explosions over a defined period of time, in a particular area in the presence of any number of simulated marine animals whose movements are constrained in three-dimensions.

PREDICTIVE MODEL FOR THE ANALYSIS OF THE EFFECTS OF UNDERWATER IMPULSIVE SOURCES ON MARINE LIFE

STATEMENT OF GOVERNMENT INTEREST

[0001] The invention described herein may be manufactured and used by or for the Government of the United States of America for governmental purposes without the payment of any royalties thereon or therefore.

CROSS REFERENCE TO OTHER PATENT APPLICATIONS

[0002] None.

BACKGROUND OF THE INVENTION

(1) Field of the Invention

[0003] The present invention relates generally to environmental impacts of acoustic sources, and more particularly to predicting the physiological and behavioral impact of underwater impulsive sources on marine animals in a defined area of a body of water.

(2) Description of the Prior Art

[0004] Prior art methods for predicting the impact of acoustic sources on marine animals have not considered the acoustic properties of multiple underwater impulsive sources such as underwater explosions. Presently the prior art consists of two quantitative methods that are used to determine the number of marine animals influenced by acoustic sources; the sonar exposure model (SEM) and the acoustic integration model (AIM). Both quantitative methods are focused on sonar acoustic impacts. Both models use a statistical distribution of animals in depth and location combined with zones of influence. Inherent to the SEM model, is a static distribution (no movement in space or time) over a fixed depth region of animals with acoustic sources moving along fixed paths. While this model gives an animal exposure estimate for the entire model run, no statistics on the exposure of each animal is available or calculable. Additionally, distribution in depth is the only animal movement behavior that can be included. Inherent to the AIM model is a simulation that moves the marine animals in depth and location according to assumed behavior. Results achieved from the AIM model is dependent on a single simulation run and on the accuracy of the input behavioral parameters. Because marine mammals are usually sparsely distributed, the density, or number per unit area, is increased by factors of 20 to 100 times that of the actual, allowing for a single simulation run resulting in a smooth distribution of animals over the defined simulation region. Later in this simulation, the number of animals affected is calculated by dividing by the increase factor. Although exposure of each animal is recorded over the simulation period, the single run does not allow for confidence interval calculation, evaluation of rare and unusual events or input accuracy effects.

SUMMARY OF THE INVENTION

[0005] Accordingly, it is an object of the present invention to provide a method for predicting the impact of impulsive acoustic sources on marine animals that consider the acoustic properties of multiple underwater impulsive sources such as explosions and seismic air guns.

[0006] It is also an object of the present invention to provide a method for predicting the impact of acoustic sources on marine animals that includes the effects of diving abilities or herding tendencies of the marine animals.

[0007] Other objects and advantages of the present invention will become more obvious hereinafter in the specification and drawings.

[0008] In accordance with the present invention, a method is provided to predict the biological consequences to marine animals from exposure to multiple underwater impulsive sources by simulating underwater explosions over a defined period of time, in a particular area in the presence of any number of simulated marine animals whose movements are modeled in three-dimensions and time. The method involves collecting relevant information for particular cases being examined, including information on the types of impulsive acoustic sources and their motion to be modeled, on the animal assemblages in the chosen area, on the environmental characteristics of the area and on the environmental regulations relevant to impulsive acoustic impacts in the area. The information is then incorporated into models of underwater explosions, of acoustic propagations and of marine animals. The exposure of each marine animal to acoustic energy is recorded and compared to exposure criteria to quantify the biological exposure effects. The quantified effects comprise exposures presented as total impacts per species and per simulated impulsive acoustic impact whether it is single or multiple impulsive acoustic impacts. The quantified biological exposure effects are then graphically illustrated.

BRIEF DESCRIPTION OF THE DRAWINGS

[0009] A more complete understanding of the invention and many of the attendant advantages thereto will be readily appreciated as the same becomes better understood by reference to the following detailed description when considered in conjunction with the accompanying drawings wherein like reference numerals refer to like parts and wherein:

[0010] FIG. 1 is a process flow diagram illustrating the method of the present invention;

[0011] FIG. 2 is an example of a dosimeter record for a single marine animal that indicates the sound pressure level exposure for each acoustic event verses time.

[0012] FIG. 3 is graph illustrating a cumulative percentage of the marine animal population exposed as a function of energy level.

DESCRIPTION OF THE PREFERRED EMBODIMENT

[0013] Referring now to FIG. 1, there is shown an impulsive acoustic environmental impact model processing flow diagram illustrating the method 10 for predicting the physiological and behavioral impact of underwater impulsive sources on marine animals in a defined area of a body of water. Method or process 10 incorporates six process components used in determining the marine animal impacts of impulsive acoustic sources.

[0014] The first process component is the exercise description component 12, which models the type of impulsive acoustic sources used and the associated use timeline. For example, the exercise description component 12 could describe and model a live fire exercise involving the bombardment of an unmanned target vessel. A live fire exercise is conducted during daylight hours and the duration may range from hours to several days. Information on the acoustic source characteristics (e.g., explosive size and net explosive weight) specific to the live fire exercise is obtained, as well as the number of impulsive acoustic source types, the number of impulsive acoustic source events, and the time interval for the impulsive acoustic source events. This information is used to predict and model the acoustic energy that propagates during intermittent underwater acoustic events (e.g., shockwave, peak pressure, energy flux density, etc.) for a predetermined exercise time line and source sequence.

[0015] A standard propagation model, like the Reflection and Refraction Multi-Layered Ocean/Ocean Bottoms with Shear Wave Effects (REFMS) if explosives are selected, is used to indicate peak pressures, positive impulse, and energy flux effects from underwater detonations associated with a live fire exercise. The REFMS model calculates the combined reflected and refracted shock wave environment for underwater explosions using a single, generalized model that is based upon Cagniard's linear wave propagation theory convolved with a nonlinear similitude source term for each explosive event.

[0016] Once the number of impulsive acoustic source types, the number of impulsive acoustic source events, and the time interval for the impulsive acoustic source events are determined, a timeline for the exercise is created. A timeline considers minimum and maximum time between individual impulsive acoustic source events, period of use for each impulsive acoustic source type and order of impulsive acoustic source use. Source events are randomly distributed in time within the minimum and maximum times.

[0017] The second process component is the biological data component 14. A complete review of available marine animal distribution and abundance in the geographic range of the area in question is performed. Sources of biological data include scientific papers that describe a particular marine animal species, or group of species, spatial and temporal distribution, abundance, habitat use, social behavior, feeding habits and other subject matter related to the ecology of the species or group of species in question. Resources for this information can be primary and gray literature, reports, and raw data from the underlying studies or surveys. The information can be used in the definition of each species. The biological data is used to estimate the potential population in the area for the season or time period of interest and the behavior of individual groups of marine animals (e.g., swim speed, diving profile, habitat associations responses to exposure or the activity).

[0018] The distribution of marine animals is generally patchy and non-random but producing a representation of non-random distribution is dependent upon the type of habitat use information available such as association with prey distributions, bathymetric regimes, sea surface temperatures, or if unpublished, can be derived from sighting, museum, and whaling records for each species.

[0019] In addition to the biological data described above, the three dimensional marine animal movement is simulated based upon known habitat use characteristics and behaviors specific to the geographic area of species present where the exercise occurs (e.g., swim speeds, migration, feeding, social behavior, depth profiles, etc.). The initial headings and locations for their paths are randomly selected for all animals. Swim speeds are appropriate for the species of animal and a statistical variation in speed is assigned to each individual based on published observation data when available. Behavioral responses to the acoustic exposures can also be programmed where appropriate. Types of responses include changes in swim speeds, heading, depth and area usage. Marine animals are populated within the exercise area at levels determined by the user, using population estimates usually based on published surveys or peer reviewed literature. Types of movement avoidance behavior previously considered include linear, potential field, swarming of flocking models.

[0020] The third process component is the oceanographic environment data component 16. Oceanographic environment data (e.g., sound speed profiles) is gathered to assess how impulsive acoustic source waveforms propagate through the body of water in which the exercise will take place. Oceanographic environment data includes locations of surface ducts, bottom types, sediment characteristics and other features affecting the way sound propagates in water. Generally, the oceanographic environment data parameters will include bathymetry, sound velocity profiles (SVPs), and bottom type parameters including sediment characteristics, compressional and shear wave speed, density, and layer depths.

[0021] The fourth process component is the acoustic propagation model component 18. Using oceanographic environment data as gathered in the third process component, an underwater acoustic model capable of creating the pressure-time histories of the impulsive acoustic sources is used to make predictions for each impulsive acoustic source type. Modeling the impulsive acoustic source type may require the ability to accurately predict non-linear and linear behavior such as those produced by explosive sources. Examples of suitable acoustic propagation models are Monterey-Miami Parabolic Equation mode (for seismic source events) and The Reflection and Refraction Multi-Layered Ocean/Ocean Bottoms with Shear Wave Effects (REFMS)for explosive sources and the Comprehensive Acoustic Simulation System/Gaussian Ray Bundle (CASS/GRAB) model for sonar sources.

[0022] The fifth process component is the exposure simulation and data collection component 20. This component combines the acoustic and marine animal movement information to predict exposures for all marine animals during an exercise by assigning a dosimeter to each simulated marine animal that records information pertinent to the acoustic environmental impact assessment. Information collected as a function of time includes acoustic exposures (sound pressure level) both total and spectral, energy flux density levels both total and spectral, peak pressure, and positive impulse. Other information collected as a function of time includes position, depth, heading, swim speed, and behavior reaction in the exercise area and slant range from acoustic events relative to the exercise area. After the start of the exercise, as individual marine animals move within the environment, the marine animals are exposed to varying intensities of acoustic energy depending on their location relative to the acoustic events (source and receiver positions). Acoustic levels verses depth and range in the test region are obtained from pre-calculated tables using the selected range dependent propagation model for the sources. Acoustic exposure information is then stored in the dosimeter assigned to each simulated marine animal over the course of the entire exercise. An example of a dosimeter record for a single animal as shown in FIG. 2 indicates the sound pressure level exposure for each acoustic event verses time.

[0023] The sixth process component is a post exercise processing module 22 to evaluate the dosimeter exposure records and translate the records into percent population exposure statistics for each animal impact criterion. The criteria for the evaluation of impacts are based on compliance with governing environmental regulations, treaties, laws (state, federal and international). The governing regulations, treaties and laws are examined to determine the allowable limits of acoustic impacts in the form of underwater pressure waves on Marine animals. Examples of relevant regulations include the Marine Mammal Protection Act and Endangered Species Act.

[0024] Several standard acoustic metrics are used for underwater pressure waves in this method to describe the thresholds for predicting potential physical impacts such as total energy flux density, positive impulse, and peak pressure. For plane waves, as assumed in this invention, energy flux density (EFD) is the time integral of the squared pressure divided by the impedance of sea water. It has standard units of Joules per meter squared (J/m^{2}) or in pounds per square inch (lb/in^2). Total EFD levels in this document are referred to as decibels referenced to 1 micro Pascal squared- second(dB re 1 μPa^2-sec). Positive impulse is the time integral of an initial positive pressure pulse. Standard units are Pascal-seconds (Pa-sec), but Pounds per square inch- milliseconds (psi-msec) are also used. There is no decibel analog for impulse. Peak pressure is the maximum positive amplitude of a pressure wave dependent on charge mass and range. Units used here are psi, but dB re 1 μPa can be used. Types of criteria can be expressed as Sound Pressure Level (SPL), sound intensity level, or an energy based criteria such as Sound

Exposure Level (SEL), energy flux density level, or energy source level.

[0025] Information collected in the dosimeters is processed and compared to the set of defined the environmental compliance criteria as set out in the governing environmental regulations to quantify the impact to the individual marine animals and to the marine animal population at large. Criteria are defined for non-accumulating or accumulating levels during the exercise to predict physical and behavioral impacts. Processing criteria consists of a maximum pressure exposure and total energy flux density exposure for all individual marine animals. Percent population energy flux density exposure distribution functions are calculated as this quantity is additive over the exercise period assuming no hearing recovery.

[0026] Ultimately the quantified impact is illustrated graphically representing the following information: The number of marine animals exposed during the total number of events, The cumulative energy exposure of all marine animals present during the first event, A histogram of the cumulative energy exposures verses the percentage of the total marine animal population, and A cumulative percentage of the marine animal population exposed as a function of energy level is illustrated in FIG. 3.

[0027] In a preferred embodiment, the six processing modules are implemented by a computer that receives as input the appropriate data displays the processed results through a graphical user interface.

[0028] The invention thus been described is a method for determining the acoustic impact of underwater acoustic sources on marine animals in a defined area of any body of water. The method includes assembling data about the environmental and acoustic characteristics of the site, about the acoustic sources to be used at the site, about marine animals known to inhabit the area and environmental compliance criteria pertinent to the site. Based on the above, acoustic modeling is performed and the areas within the site having acoustic energy levels above the environmental compliance criteria are identified.

[0029] It will be understood that many additional changes in the details, materials, steps and arrangement of parts, which have been herein described and illustrated in order to explain the nature of the invention, may be made by those skilled in the art within the principle and scope of the invention as expressed in the appended claims.

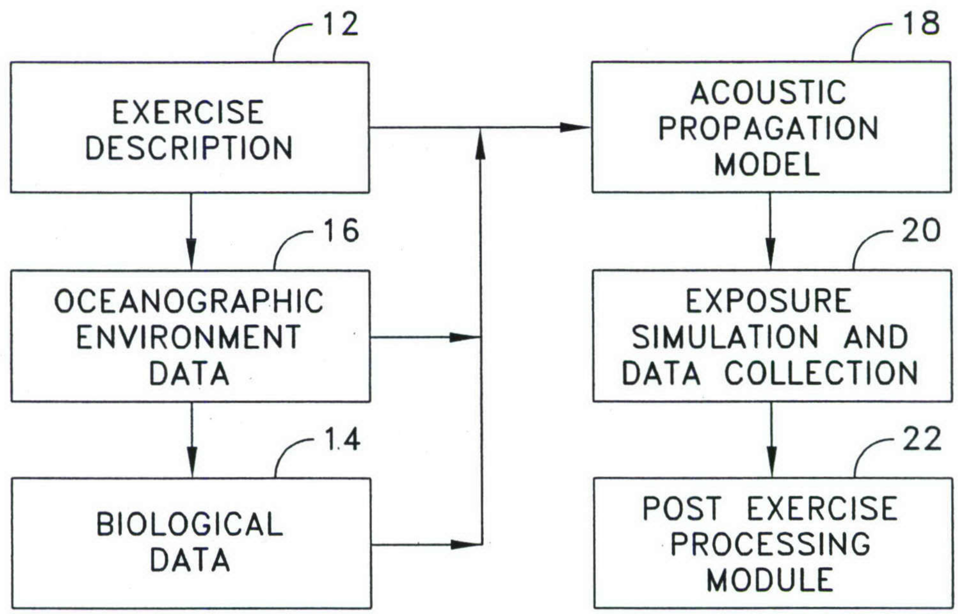
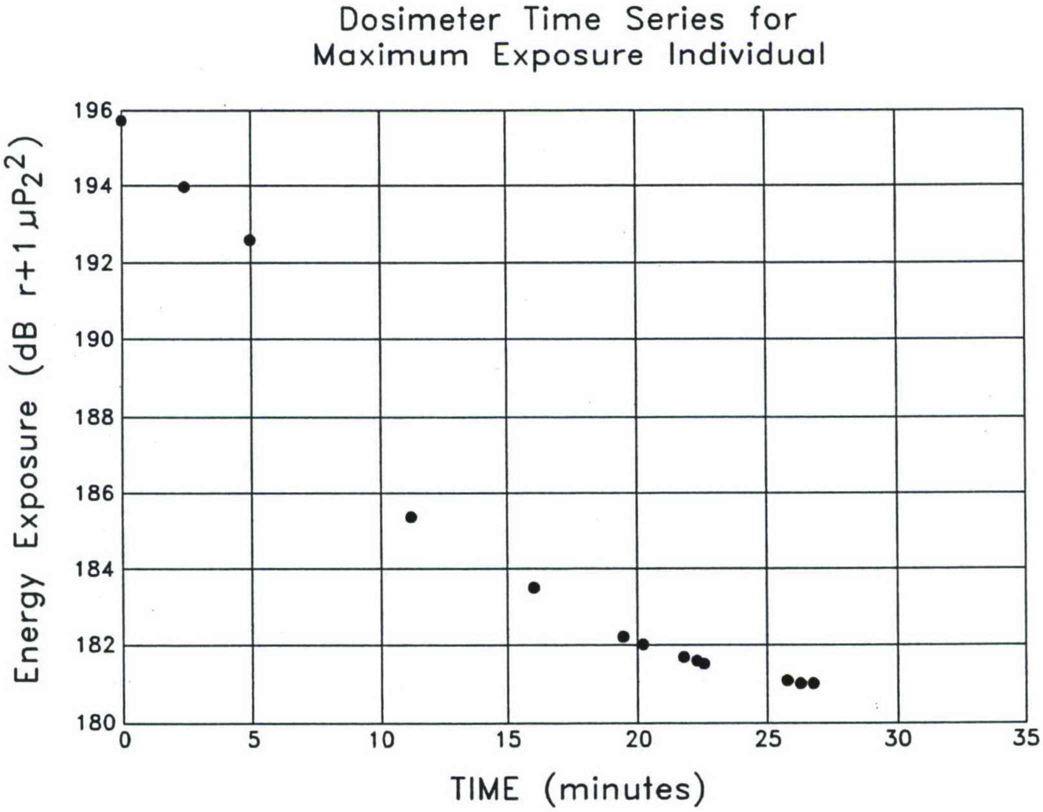
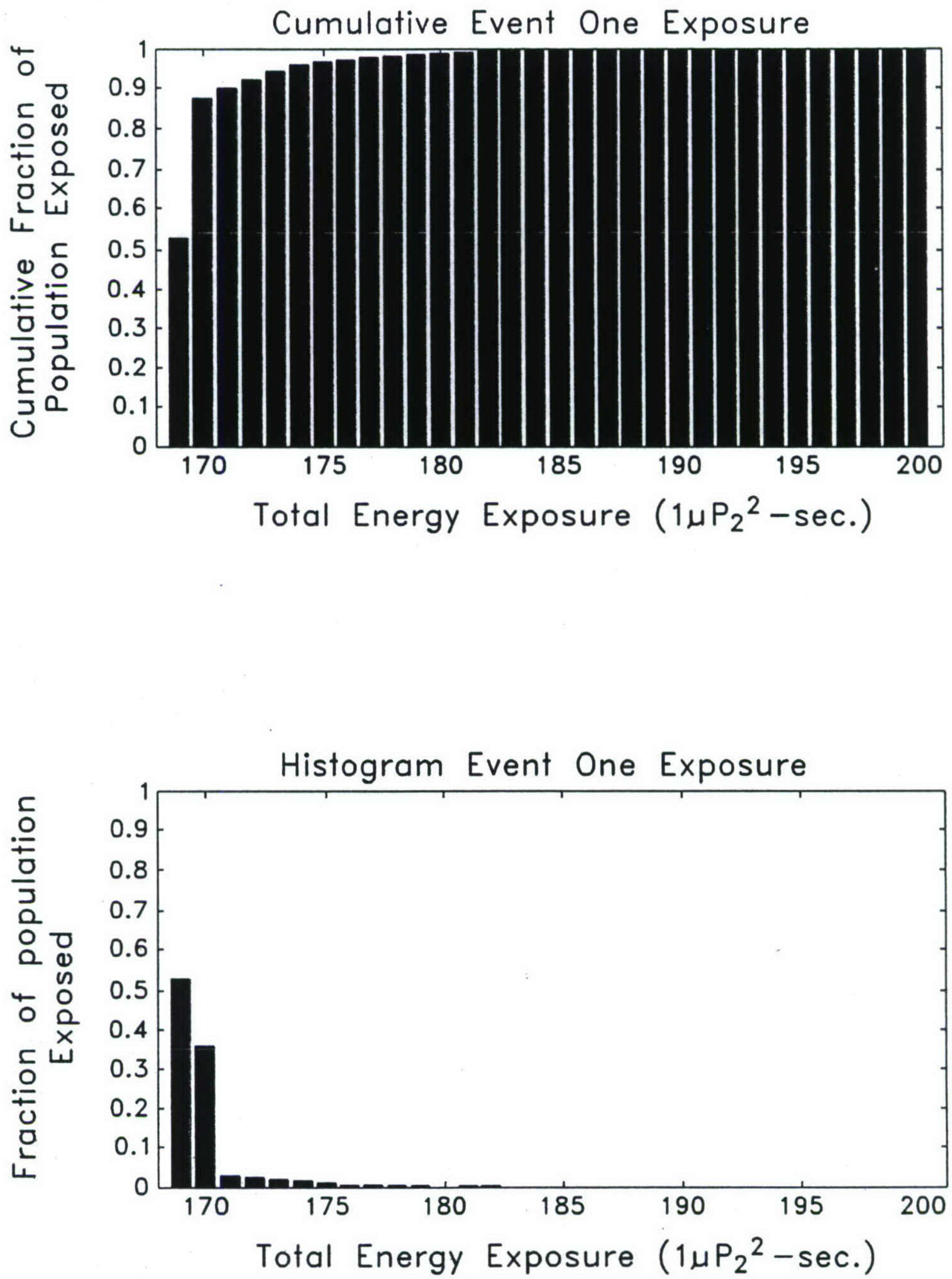

12
EXERCISE DESCRIPTION
16
OCEANOGRAPHIC ENVIRONMENT DATA
14
BIOLOGICAL DATA
18
ACOUSTIC PROPAGATION MODEL
20
EXPOSURE SIMULATION AND DATA COLLECTION
22
POST EXERCISE PROCESSING MODULE

FIG. 1



Dosimeter Record of SPL Exposure vs. Time

FIG. 2


Cumulative Event One Exposure
Cumulative Fraction of Population Exposed
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0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
170
175
180
185
190
195
200
Total Energy Exposure (1μP2² −sec.)
Histogram Event One Exposure
Fraction of population Exposed
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
170
175
180
185
190
195
200
Total Energy Exposure (1μP2² −sec.)

FIG. 3