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An Evaluation of the Approaches Used To Predict Potential Impacts of Open Loop LNG Vaporization Systems on Fishery Resources of the Gulf of Mexico

Prepared for

The Center for Liquefied
Natural Gas—Seawater
Usage Technology
Committee

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Seawater Usage Technology Committee
1220 L Street NW, 9th Floor
Washington, DC 20005

Prepared by

R. Dreas Nielsen, Thomas C. Ginn, Ph.D.,
Linda M. Ziccardi, and Paul D. Boehm, Ph.D.

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Acronyms and Abbreviations

DEIS	draft environmental impact statement
DMS	U.S. Department of Transportation Docket Management System
DWPA	Deepwater Port Act
EFH	essential fish habitat
EIS	environmental impact statement
ELS	early life stage
GOM	Gulf of Mexico
GSMFC	Gulf States Marine Fisheries Commission
LNG	liquefied natural gas
MARAD	U.S. Department of Transportation Maritime Administration
NEPA	National Environmental Policy Act
NGO	non-governmental organization
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
OLV	open loop vaporization
SCV	submerged-combustion vaporizer
SEAMAP	Southeast Area Monitoring and Assessment Program
USCG	U.S. Coast Guard

Executive Summary

This study was commissioned to develop an independent evaluation of the technical work that has been done to date in assessing environmental impacts from liquefied natural gas (LNG) terminals in the northern Gulf of Mexico (GOM) that propose to use open loop vaporization (OLV) technology to regasify the LNG into natural gas. The primary environmental issue associated with the use of OLV technology in the GOM is the potential for impacts on fish populations resulting from entrainment (carrying of smaller organisms including planktonic eggs and larvae of fish and invertebrates into the system with the seawater) and impingement (the retention of larger fish and other organisms on the intake screens) associated with the seawater intakes.

Objectives of the Study

The objectives of this evaluation were to:

- Review and characterize the available information concerning the occurrence of early life stages (ELSs) of fishes in the northern GOM
- Review life history information for key fish species that is used in the ichthyoplankton assessment models of the environmental impact statements (EISs)
- Assess and quantify to the extent possible the uncertainty and scientific validity of assumptions used in the EISs for predicting losses of key fish species
- Assess the uncertainty and scientific validity of conclusions reached in the EISs as they relate to key fish species and ecosystem impacts
- Analyze the comments received and additional analyses performed by various commenters on the EISs
- Develop recommendations and examples for valid scientific assessment techniques that can be used to better assess the potential impacts of LNG facilities on ecological resources of the northern GOM.

Study Approach

The draft and/or final EISs were compiled and reviewed for adequacy, for appropriateness of methods and models, and accuracy. Fisheries impact predictions were evaluated for their degree of conservatism (i.e., tendency to overpredict risks), inherent biases, and relative uncertainty of scientific assumptions. Mitigation plans included in the project designs (e.g., intake screen mesh sizes, seawater intake velocities, location of intakes and outfalls) were also evaluated to determine the adequacy of proposed measures for offsetting fisheries impacts.

Exponent also reviewed the amount, adequacy, and coverage of the Southeast Area Monitoring and Assessment Program (SEAMAP) fisheries data, upon which impact predictions in the EISs are based. The available data for eggs and larvae of key species were evaluated for spatial and temporal coverage, vertical distribution, and correspondence of data collection sites with the location of LNG terminals. Agency and non-governmental organization comments on the EISs were also reviewed to evaluate public concerns regarding fisheries impacts from the use of OLV technology, and to assess the basis for and validity of the opposition to the use of this technology in the northern GOM. In addition, relevant reports and publications from the scientific literature were also reviewed, such as analogous studies conducted for power plants and studies on the distribution of fish eggs and larvae in the GOM. Information on the life history characteristics of key species was also evaluated, especially as it relates to estimated mortality rates and the durations of ELSs for key fish species.

Major Findings

1. **The SEAMAP database that forms the basis of the impact prediction is adequate for use in the calculation of egg and larval abundances potentially affected by the proposed LNG facilities and for use in these impact predictions. The data are limited in certain respects, and the way in which the data were handled leads to overestimates of fish abundance and entrainment. These limitations affect the scientific uncertainty of the impact assessments and the relevance of some of the comments received.**

   Most importantly, the methods used in the EISs to analyze SEAMAP data for incompletely identified taxa[1] and to account for seasonal occurrences resulted in overestimation of larval abundances and of uncertainties (i.e., upper confidence limits). These problems with data analyses, in turn, result in corresponding overestimates of entrainment mortalities that are subsequently used as inputs to the ichthyoplankton assessment models.

2. **The adult-equivalent modeling approach used in the EISs, which projects egg and larval abundances to weights of adult fish, contains mathematical errors, data analysis defects, and conceptual flaws. The net result is that the models substantially overpredict fish mortality. The model results also have a potentially large uncertainty because of the lack of information and inherent uncertainties associated with mortality rates and life stage durations of key fish species. The modeling approach**

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[1] In all ichthyoplankton (i.e., fish egg and larvae) studies, some eggs and larvae cannot be identified to species and must be classified at a higher taxonomic level such as family. In such cases, abundances of species must be estimated using the higher level data.

is also inconsistent with the stock assessment methods that are used to assess fishing impacts.

The adult-equivalent approach uses estimates of fish mortality rates that are not well known and that contribute a substantial amount of uncertainty, and potentially bias, to the impact assessments. The approach also neglects the effects of population size on reproductive success. The approach also inappropriately compares projected adult-equivalent weights to fishery landings; landings are not indicative of fish population size, and the fishery landing statistics used are inappropriate. Because of these problems with the assessment approach, the estimates of impacts are biased high and result in an overstatement of potential population-level effects of LNG facilities on fishery resources.

Instead of an adult-equivalent (forward projection) approach, the impact assessments should use an egg-equivalent (fecundity or hindcasting) approach, in which total entrainment losses of ichthyoplankton are related to losses of egg production at the population level. Such assessments can be conducted with available data, do not require as many uncertain estimates of mortality rates, and provide more meaningful and interpretable endpoints, especially for key species such as red drum and red snapper. This approach is also compatible with stock assessment methods that are used to evaluate fish populations as a whole. Application of egg-equivalent and fecundity hindcasting models to red drum at Gulf Landing indicate that the EIS has greatly overpredicted mortality.

The EIS predicts annual red drum mortality equivalent to approximately 28,000 age-1 equivalent fish (e2M 2005, Table G-14). In contrast, a corrected model predicts mortality of 5,600 age-1 equivalent fish or 8 spawning females. The difference between these two estimates is a result of the inclusion of uncertain life history parameters for juvenile fish in the age-1 equivalent estimate. The age-1 equivalent estimate is therefore more uncertain than the fecundity estimate. This uncertainty evidently takes the form of a positive bias (overestimate) in the estimated impact. The EIS estimate of impact is 1,750 times higher than the more accurate fecundity-based estimate. The known biases account for part of this overprediction. Some of the other sources of uncertainty described previously may impose additional bias that accounts for the remainder of the overprediction.

3. **Overall, the data inputs, assumptions, and modeling approaches used in the EISs substantially overestimate the potential for adverse impacts of LNG facilities—for individual facilities as well as cumulative impacts from multiple facilities.**

The EISs result in overestimates of adverse effects because an abundance of caution (i.e., conservative assumptions) has been used at various stages of the assessments in dealing with the uncertainties associated with available information. Because most of the limitations of the analyses conducted to date result in overestimates of mortality, the conclusions of the EISs that OLV usage will have minor impacts on GOM fisheries would be supported by a more scientifically rigorous analysis. Likewise, the predictions by some commenters on the EISs of substantial cumulative impacts on GOM fisheries are not likely to be upheld by a more rigorous analysis.

4. **The analyses conducted in the EISs, while limited in some respects and highly conservative in nature, are sufficient to make licensing decisions concerning operation of LNG facilities using OLV systems.**

   Because of the overpredictive nature of the assessments, actual impacts will be substantially less than the impacts predicted in the EISs. Thus, the EISs conclusions that impacts will be minor are very conservative, and can be used for licensing decisions with appropriate recognition given to the degree of conservatism. Moreover, the upper bound estimates of impacts contained in these assessments, especially when compared with fishery landings data, are so highly unlikely to occur that they are irrelevant to scientifically-based decisions. The information gained from post-operation monitoring programs at these facilities will serve to reduce the inherent uncertainties associated with current data and enable refinement of operations to minimize any impacts on fishery resources.

Recommendations

There are scientifically valid approaches that could be used to develop more appropriate and meaningful estimates of entrainment impacts at LNG facilities. The goal of such analyses would be to use alternative scientific approaches that would include valid endpoints for impacts on fishes and associated quantitative assessments of uncertainty as part of impact assessments. A reanalysis of the potential impacts of LNG facilities on fishes could be conducted following the collection of site-specific monitoring data for licensed facilities. For future studies of the potential impacts, such assessments would include the following:

- Analysis of the temporal, spatial, and vertical distribution of eggs and larvae of key species, including a sample-specific evaluation of taxonomic uncertainty
- Reassessment of population parameters (e.g., instantaneous mortality rates and life stage durations) for ELSs of fishes, possibly by a panel of fisheries experts
- Quantification of cumulative impacts using probabilistic analysis to compensate for and/or quantify uncertainties
- Use of an equivalent egg abundance endpoint for predicting impacts to fishery resources, including comparisons with individual and population-level fecundity data and as inputs in stock assessment models where available.

1 Introduction

Numerous liquefied natural gas (LNG) terminals have been proposed for construction and operation in the Gulf of Mexico (GOM) and elsewhere in the United States. Each project includes some technology for converting the liquid natural gas back into the gaseous state (i.e., regasification). Seven such LNG Deepwater Port Act of 1974 (DWPA) applications have been filed with the U.S. Department of Transportation Maritime Administration (MARAD) for terminals in the northern GOM that either currently use or propose to use open loop vaporization (OLV) regasification technology (MARAD 2005), described below. Third party environmental impact statements (EISs) prepared by contractors for the U.S. Coast Guard (USCG) and MARAD as part of the LNG ports' licensing process have concluded that environmental impacts from the facilities will be minor (USCG and MARAD 2003, 2004a, 2005a–d) and will not likely be significant at the population level (USCG and MARAD 2004b). As part of the EIS process, a substantial number of comments were received concerning the potential impacts of these facilities, especially potential impacts to fisheries in the GOM. Many of the comments center on the characterization of impacts to key fishery resources such as red drum (*Sciaenops ocellatus*) that result from the entrainment of early life stages (ELSs) (e.g., eggs and larvae) in the seawater used by the OLV systems for vaporization of LNG. Of particular focus are the models used in the EISs to predict potential reductions in fish stocks as a result of entrainment, and comparison of those potential stock reductions to commercial and recreational landings of red drum and other species.

This report provides an independent ecological review of the analyses performed to date regarding potential project-specific and cumulative impacts of the use of OLV technology on important fishes of the GOM. The overall goal of this investigation is to develop an assessment and a critique of the approaches used to date by evaluating the underlying scientific data and methods used by the various parties (i.e., EIS contractors, government scientists) to determine if the various analyses result in valid and interpretable predictions of the risks to key fish species in the northern GOM.

1.1 Overview of Regulatory Status

USCG and MARAD have jurisdiction under the DWPA for the siting and operation of offshore LNG facilities in federal waters.[2] The eight offshore LNG terminals existing in or proposed for the GOM fall under the jurisdiction of these agencies. As part of the DWPA application process, in addition to public safety and security regulatory requirements, USCG and MARAD must prepare an EIS for each new LNG terminal to fulfill the requirements of the National Environmental Policy Act (NEPA). Other statutory requirements as part of the NEPA analysis include compliance with Section 307 of the Coastal Zone Management Act, Section 7 of the

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[2] The Federal Energy Regulatory Commission has jurisdiction over onshore LNG facilities and offshore facilities in state waters.

Endangered Species Act, Section 106 of the National Historic Preservation Act, and the Magnuson-Stevens Fishery Conservation and Management Act.

The eight LNG terminals using OLV technology either licensed or proposed for the GOM and their regulatory status are as follows (MARAD 2005):

- Beacon Port, 50 miles east-southeast of Galveston, Texas: Application released December 2004. Notice of Application issued May 2005; undergoing public scoping process.
- Compass Port, 11 miles south of Dauphin Island, Alabama: Draft EIS (DEIS) submitted in February 2005; license under review.
- Gulf Gateway Energy Bridge, 116 miles off the coast of Louisiana: Licensed in May 2004 and in operation. Regasification is done on board specially designed vessels, using a shell and tube vaporizer, part of a combined open/closed loop system.
- Gulf Landing, 38 miles offshore of Louisiana: Final EIS issued February 2005; license granted.
- Main Pass Energy Hub, 16 miles off the coast of Louisiana: DEIS issued June 2005; license under review.
- Pearl Crossing, 41 miles south of the Louisiana coast: DEIS issued April 2005; application withdrawn October 2005.
- Port Pelican, 36 miles off the coast of Louisiana: License issued January 2004.
- Terminal Offshore Regas Plant, 50 miles south of Dauphin Island, Alabama: Permit applications will be submitted in late 2005, and no EIS has yet been prepared.

1.2 Statement of the Issue

1.2.1 Background on LNG Facilities and OLV Technology

The U.S. Energy Information Administration has forecast that the United States demand for natural gas will increase more than 38 percent by 2025. Because domestic natural gas production has been estimated to be at or past its peak, importing LNG is gaining a greater focus towards meeting the U.S. energy demands (FERC 2005). LNG is natural gas that is super-cooled to approximately –260°F at normal air pressure. The natural gas is converted into liquid by refrigeration. This process of liquefaction, which dates back to the 19th century, reduces the volume of gas by approximately 600 times, making it possible to economically transport the gas around the globe in specially designed ships. These tankers transport the LNG to offshore and onshore terminals, where vaporizers are used to heat the LNG, converting the liquid back to a gas.

There are several types of regasification systems available, the primary two being 1) submerged-combustion vaporizers (SCVs), and 2) OLV, which includes open-rack vaporizers and shell and tube systems. In addition, closed loop systems are also designed for use on a new fleet of LNG carriers operating at submerged turret loading buoys in deepwater offshore locations. SCVs burn a portion of the regasified natural gas product to heat water in a closed loop submerged heating system. OLV uses seawater at ambient temperature to heat and regasify LNG. The heat exchangers in an OLV system are open to the surrounding environment, which is why they are also referred to as open loop systems. In an open loop system, seawater is cooled by the warming of the LNG and then discharged to the environment at approximately 13 to 22°F below the ambient seawater temperature. Sodium hypochlorite is usually injected at the pump to prevent marine growth on the water intakes and inside the water system (USCG and MARAD 2004a). Of the eight LNG terminals either currently licensed or proposed for the GOM, six use gravity-based OLV systems and one (Gulf Gateway Energy Bridge) uses a combined open/closed loop system where regasification is performed aboard specially designed vessels. Each of the OLV systems either existing or proposed for the GOM uses on an order of 100 million gallons per day (annual average) of seawater per billion cubic feet of capacity to vaporize the LNG.

1.2.2 The Environmental Question

The primary environmental question associated with the use of OLV technology in the northern GOM is the potential for impact on fish populations due to the entrainment (carrying of smaller organisms including planktonic eggs and larvae of fish and invertebrates into the system with the seawater) and impingement (the retention of larger fish and other organisms on the intake screens) associated with the seawater intakes. Entrained organisms are subject to mechanical stresses by physical contact with system components as well as chemical effects from exposure to the sodium hypochlorite used in anti-fouling. In the EISs, it is assumed, *a priori*, that 100 percent mortality occurs for all entrained organisms.

The potential impact on fishery stocks resulting from mortality of entrained eggs and larvae is the central issue in the ongoing opposition to the OLV technology in the GOM (Blanco 2005). Adding to the assessment complexities is the fact that such entrainment would take place in an environment of significant natural variability, including other stressors, and one that is influenced by a very large normal mortality of ELSs of fish driven by natural processes. In addition, any impacts from OLV would occur on a very small geographic scale compared to that in which fish eggs and larvae are naturally found in the GOM. Nevertheless, the large amount of seawater processed by individual and multiple LNG facilities gives rise to a need to understand the science involved in order to be able to quantitatively predict whether the potential impacts from OLV systems have a real scientific basis for concern. Thus, scale, perspective, and natural factors, including natural compensatory mechanisms[3] in response to the mortality from the OLV, need to be considered as part of an objective and valid ecological assessment. From a scientific standpoint, the key issues in the present assessment are the scientific validity of and uncertainties associated with extrapolation of estimated mortalities of the ELSs of fishes to comparative measures (e.g., related to stock fecundity, age-1 equivalents, or harvest equivalents) that may be used to put the predicted effects into perspective. Put simply, the key question is how well the EISs assess the likely impacts and ascribe significance to these impacts.

The EISs have relied on the Southeast Area Monitoring and Assessment Program (SEAMAP) database, which is the major source of data on egg and larval densities that are fed into ichthyoplankton assessment models to calculate potential entrainment impacts on fish eggs and larvae associated with the OLV warming water systems. These models estimate the density of larvae and eggs that might be entrained by the LNG terminals and then apply those numbers to estimate potential impacts on fish species of concern, expressed as adult-equivalent weights. As with any databases and models that attempt to estimate ecological conditions, there may be basic underlying shortcomings in the database and assumptions and hence uncertainties in the models that may result in under- or overestimation of true environmental conditions. Do such assumptions and uncertainties cast doubts on the impact analyses performed or in the critique of the impact analyses submitted by others as part of the comments to the EISs? In the case of the ichthyoplankton assessment models (i.e., adult-equivalent models), do these assumptions and uncertainties and flaws result in a valid estimation of potential impacts?

The major question being addressed in this study of the potential impacts of OLV systems is as follows:

> Does the existing science support the conclusion that predicted impacts to fisheries from the entrainment of plankton within the proposed seawater intakes of LNG facilities in the GOM are ecologically insignificant?

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[3] The primary compensatory mechanism for fish species is production of many more eggs than necessary to sustain the population. This excess fecundity compensates for losses of eggs and larvae from predation, competition, food limitation, transport out of suitable habitat, and other physical and ecological factors.

2 Study Approach

2.1 Study Objectives

The overall major objective of this work was to conduct an independent scientific evaluation of the current assessments of potential impacts to fisheries from the entrainment of plankton within the seawater intakes of LNG facilities in the northern GOM. Specific objectives of this study were as follows:

- Review and characterize the available information concerning the occurrence of ELSs of fishes in the northern GOM
- Review life history information for key fish species that is used in the EIS ichthyoplankton assessment models
- Assess the magnitude of uncertainty associated with assumptions used in the EISs for predicting losses of key fish species
- Assess the magnitude of uncertainty associated with conclusions reached in the EISs as they related to key fish species and potential ecosystem impacts
- Develop recommendations for valid scientific assessment techniques that can be used to better assess the potential impacts of LNG facilities on ecological resources of the northern GOM.

2.2 Review of Available Information

The U.S. Department of Transportation Docket Management System (DMS) is available online at http://dms.dot.gov/. All reports in the public domain related to the licensing of LNG terminals in the GOM that use OLV regasification technology are available from the DMS. These include the environmental reports and EISs, comments received on the EISs during the public comment period, and DWPA license applications for the LNG terminals. Other information that was compiled and reviewed included commentaries from non-governmental organizations (NGOs) such as conservation organizations and citizen action groups, news articles, and information from the scientific literature. These sources of information are described below. A complete bibliography of all documents reviewed for this study is provided as Attachment 1.

2.2.1 Environmental Impact Statements

All reports in the public domain related to the licensing of the Beacon Port, Compass Port, Gulf Gateway Energy Bridge, Gulf Landing, Main Pass Energy Hub, Pearl Crossing, Port Pelican, and Terminal Offshore Regas Plant LNG terminals (i.e., all the GOM existing and proposed terminals that use OLV regasification technology) were obtained from the DMS. The environmental reports and EISs were compiled and reviewed for adequacy, for appropriateness of methods and models, and accuracy. This review focused on the environmental consequences, cumulative potential impacts, mitigation measures, and the ichthyoplankton assessment models and model assumptions. Fisheries impact assessments contained in the EISs were evaluated with respect to their methods and assumptions, and the resulting accuracy and precision (i.e., bias and uncertainty) of their predictions. Mitigation plans that were included in the project designs (e.g., intake screen mesh sizes, seawater intake velocities, location of intakes and outfalls) were also evaluated to determine the adequacy of such measures for mitigating potential impacts.

The impact assessments for fisheries used in the EISs rely on two fundamental kinds of information:

- Abundance of ELSs of fish (i.e., eggs and larvae) that is expected to occur in the vicinity of the LNG facilities
- Life history characteristics (mortality rate and life stage duration) for fish species that are used to estimate the survival from eggs to age-1 individuals.

For the abundance information, we reviewed the amount, adequacy, and coverage of the National Oceanic and Atmospheric Administration (NOAA) National Marine Fisheries Service (NMFS) ELS data for fishes. This data set is available from SEAMAP and is the data upon which EIS impact predictions are based. The available data for ELSs (eggs and larvae) of key species were evaluated for spatial and temporal coverage, vertical distribution, and correspondence of data collection sites with the location of LNG terminals using OLV technology.

The data used in the EISs for fish life history characteristics were extracted from publications in the scientific literature. Information on estimated mortality rates and life stage durations for eggs, larvae, and juveniles is estimated based on field studies of key species. However, these kinds of information are never known with certainty, even for important species such as red drum and red snapper. Many of the studies are older investigations of a specific stock. Estimates are based on relative abundance of life stages and the data are subject to sampling uncertainties and interpretations on the part of the original investigator and the reviewer of the scientific article being used to develop the estimate. It is also important to note that these uncertain variables have a large influence on the ultimate estimate of age-1 fishes that result from a given number of eggs or larvae.

2.2.2 Comments on EISs

Agency and NGO comments on the EISs were also compiled and reviewed from the DMS web site. These include comments from NOAA's NMFS (primarily from the Southeast Regional Office and the Southeast Fisheries Science Center), state agencies (e.g., Department of Wildlife and Fisheries), the Gulf States Marine Fisheries Commission (GSMFC), the Gulf of Mexico Fishery Management Council, and NGOs such as the Sierra Club and RodnReel.com. These comments were reviewed to evaluate public concerns regarding potential fisheries impacts from the use of OLV technology, and to assess the basis for and validity of arguments in opposition to the use of this technology in the northern GOM.

2.2.3 Other Relevant Information

Other relevant reports from the scientific literature were also reviewed such as analogous studies conducted for power plants with water intakes that cause similar potential impacts (i.e., entrainment and impingement) and studies on the distribution of fish eggs and larvae in the GOM. Information on the life history characteristics of key species was also evaluated, especially as it relates to estimated mortality rates and ELS durations of key fish species.

2.3 Identification of Key Issues

Based on our understanding of the problem and the current controversy and using information from all the above-mentioned sources, we compiled a list of issues associated with the impact assessments (i.e., environmental reports and EISs) conducted to date. The list of issues was narrowed down to identify "key issues."

The key scientific issues associated with the impact assessments were found to be primarily associated with the adequacy of the fisheries database used to provide input parameters for the ichthyoplankton models, and with validity of the models themselves as far as their ability to predict potential fisheries impacts. Other issues are associated with the approach used to assess cumulative potential impacts (i.e., impacts from multiple facilities) and the effectiveness of the proposed mitigation measures. The key issues associated with assessing potential impacts to GOM fisheries from the use of OLV technology are summarized below:

- **The adequacy of the SEAMAP database.** Do the data adequately characterize the seasonal, horizontal, and vertical distribution of ELSs relative to the locations of the existing and proposed LNG terminals?
- **Adequacy of life history data for key fish species.** Are the life stage durations and mortality rates supported by the scientific literature? What is the level of uncertainty associated with these data?
- **The appropriateness of the ichthyoplankton assessment modeling approach.** How does the inherent variability of key model inputs propagate

through and influence the validity and uncertainty of the model outputs? How appropriate are the endpoints used in predicting effects (e.g., age-1 equivalents, equivalent yield)?

- **The methods used to assess cumulative potential impacts.** Have the cumulative impacts assessments been conducted rigorously? What is the best method to account for cumulative impacts of multiple facilities that would simultaneously be causing potential impacts in the GOM? Can geographic limits of individual stocks be identified for key species?

- **The effectiveness of the proposed mitigation measures.** Do the predicted results of the impact assessments consider the mitigation measures that have been built into the designs and locations of the seawater intake systems? Are adequate mitigation measures and monitoring plans in-place to offset adverse effects from potential impacts?

The EISs for LNG facilities have evaluated potential impacts to several fish species, including red drum, red snapper, gulf menhaden, and bay anchovy. As part of the screening process for this report, red drum were identified as a key species because of their recreational and commercial importance, because they have suffered from overfishing and are the focus of current recovery plans in the GOM, and because they have received a great deal of attention in the current scientific debate. For this reason, red drum are used as a primary example of the evaluations conducted in this report. However, the conclusions reached on valid assessment techniques and recommendations for future work would apply to other key species of fish in this area.

3 Findings

3.1 Use and Adequacy of the SEAMAP Database

EISs for the proposed OLV facilities have estimated fish losses using data collected as part of SEAMAP, administered cooperatively by GSMFC and NMFS Southeast Regional Office. The SEAMAP data set contains measured abundance of fish eggs and larvae (ichthyoplankton) from throughout the GOM, collected over a period of more than two decades. Overall, the SEAMAP data set is adequate for use in characterizing the affected environment and useful for predicting potential impacts from OLV facilities. However, these data also have some significant limitations that introduce a large uncertainty into the impact predications.

The strengths of the SEAMAP data set are its geographic coverage, its temporal duration (from 1982 to 2003), the use of consistent sampling methods throughout, and identification of larval fish to the level of species wherever possible. The distribution of SEAMAP samples used for ichthyoplankton abundance estimates[4] is shown in Figure 3-1 relative to the facilities, and the distribution of SEAMAP data adjacent to individual facilities is shown in Figures 3-2 through 3-5. The following are some limitations of the data set that are particularly relevant to prediction of potential impacts from OLV facilities:

- The absence of depth-stratified samples as a result of the collection method
- The proportion of larvae that could not be identified at the species level
- The absence of species-specific information for eggs
- Limitations in the temporal coverage in the vicinity of a specific facility as a result of irregular timing and locations of collections.

These limitations can increase the uncertainty, or potentially impose a bias, on the results of data analyses conducted using this data set.

The SEAMAP data set is the most comprehensive information available of ichthyoplankton abundance and distributions in the northern GOM. There is no clearly better alternative for use in assessing the potential entrainment impacts of OLV LNG facilities. The decades-long data collection represented by the SEAMAP data set supports an assumption that the data represent average long-term conditions. Consequently, the SEAMAP data set is an adequate basis for estimating potential ichthyoplankton impacts, and further use of the SEAMAP data set for these purposes is recommended. The limitations of the data set should be considered when evaluating the results of such impact assessments, however, particularly the effects on uncertainty and the

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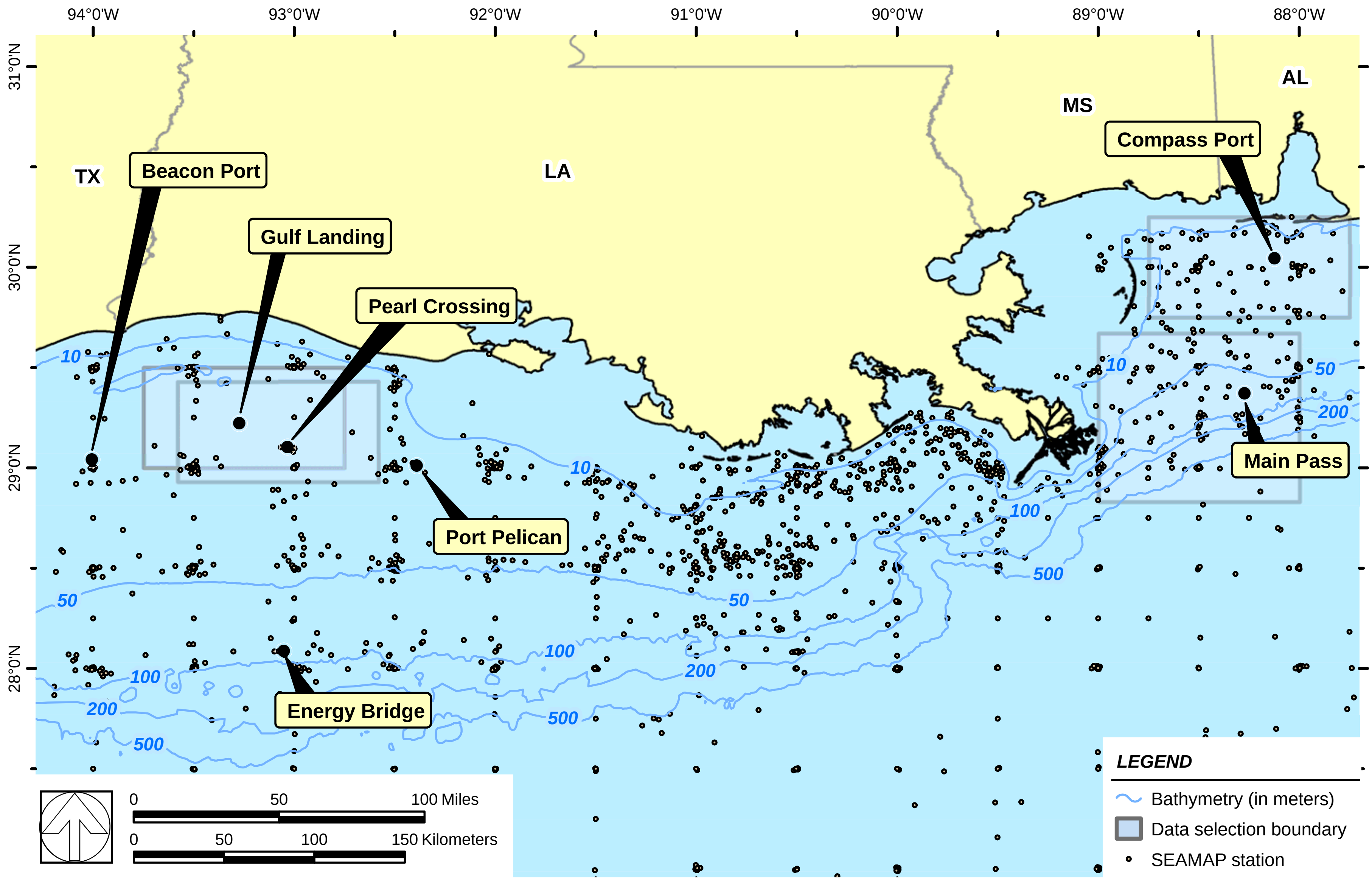
[4] This is a subset of all SEAMAP data consisting of samples collected with Bongo nets for which flow volumes were recorded. The same subset is shown on all maps of SEAMAP data in this report.



Note: Data are from all years.

Source: NOAA's National Coastal Data Development Center

Figure 3-1. Study areas with SEAMAP locations

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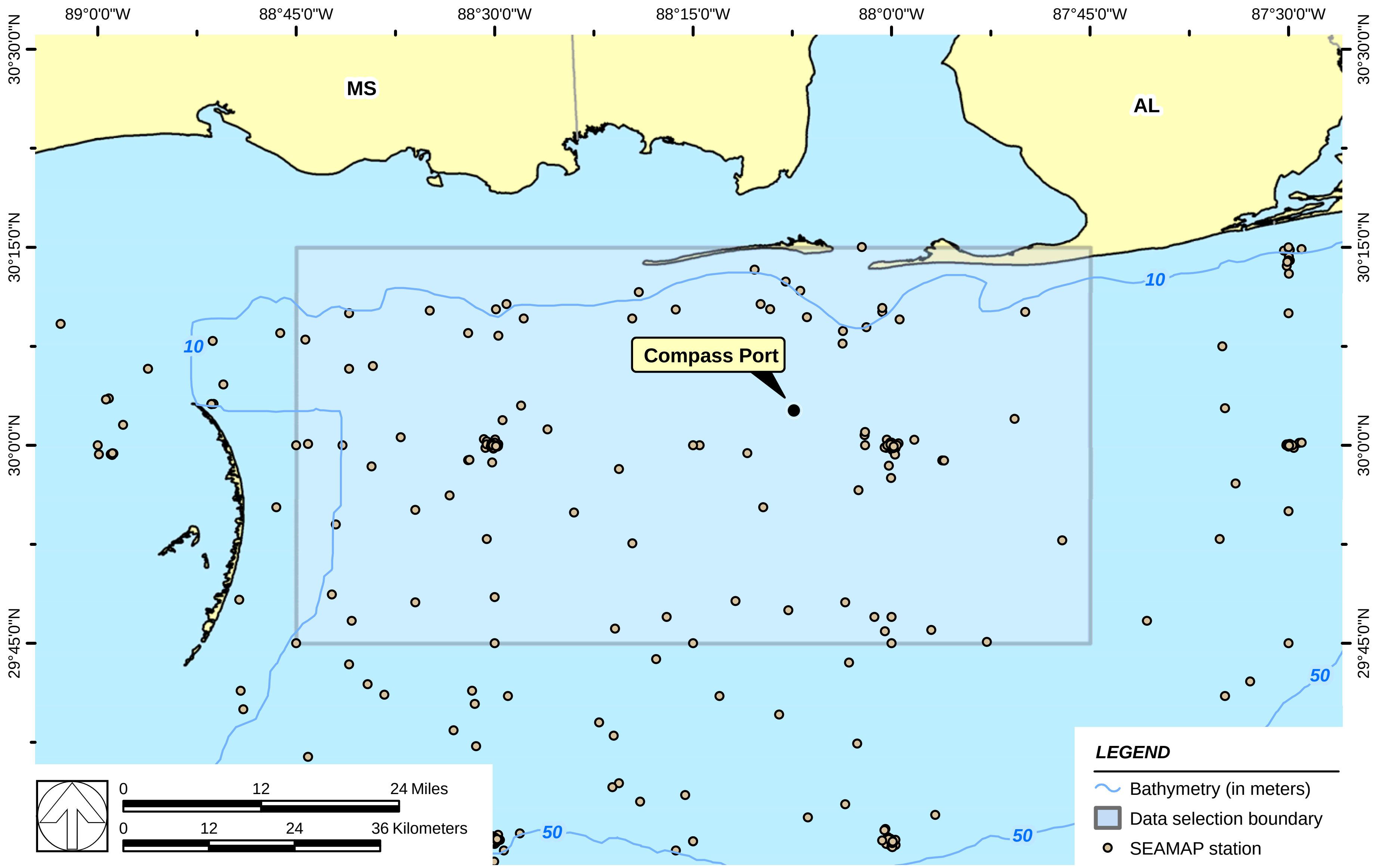

Note: Data are from all years.

Source: NOAA's National Coastal Data Development Center

Figure 3-2. Compass Port facility with SEAMAP stations

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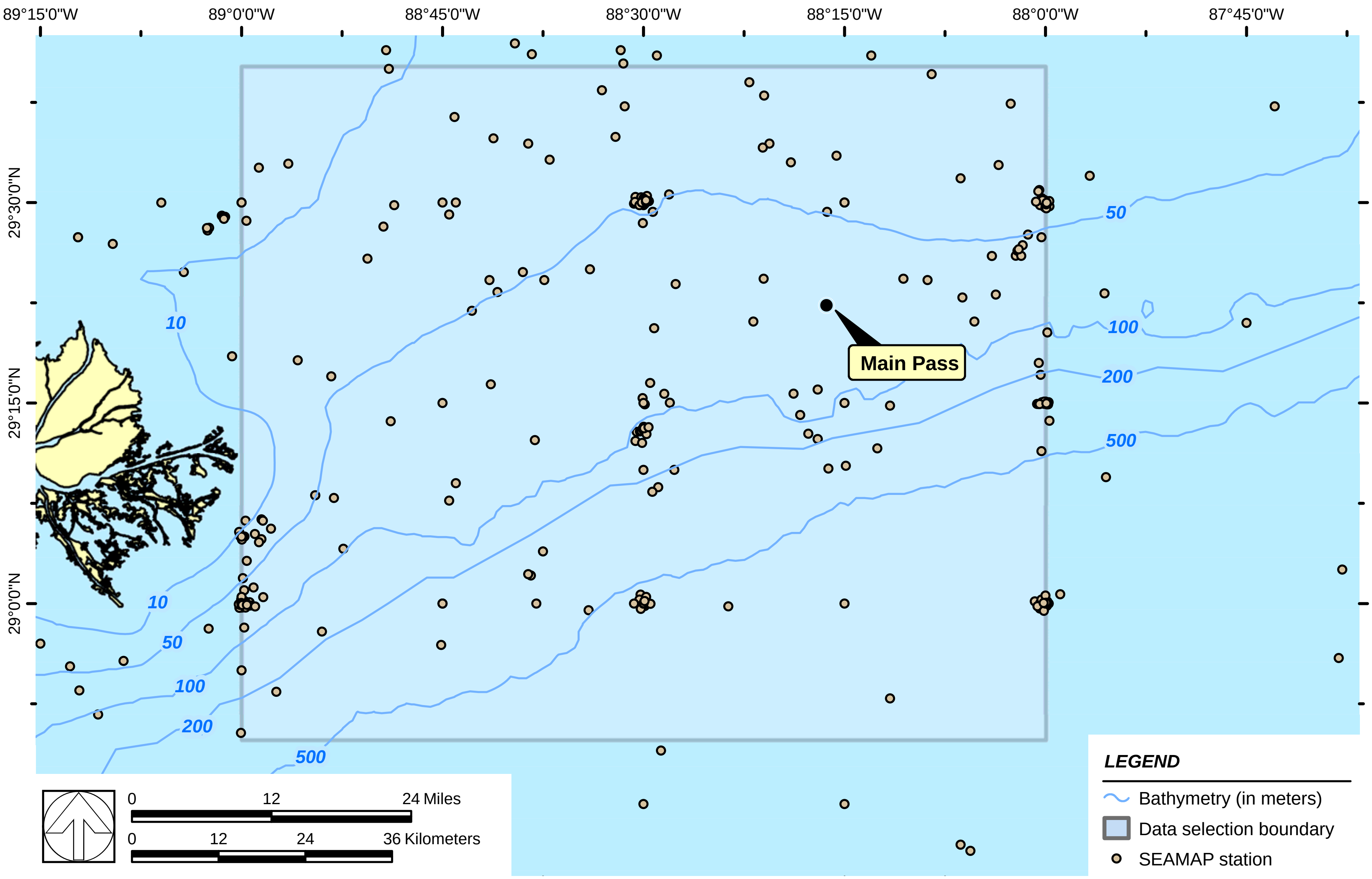
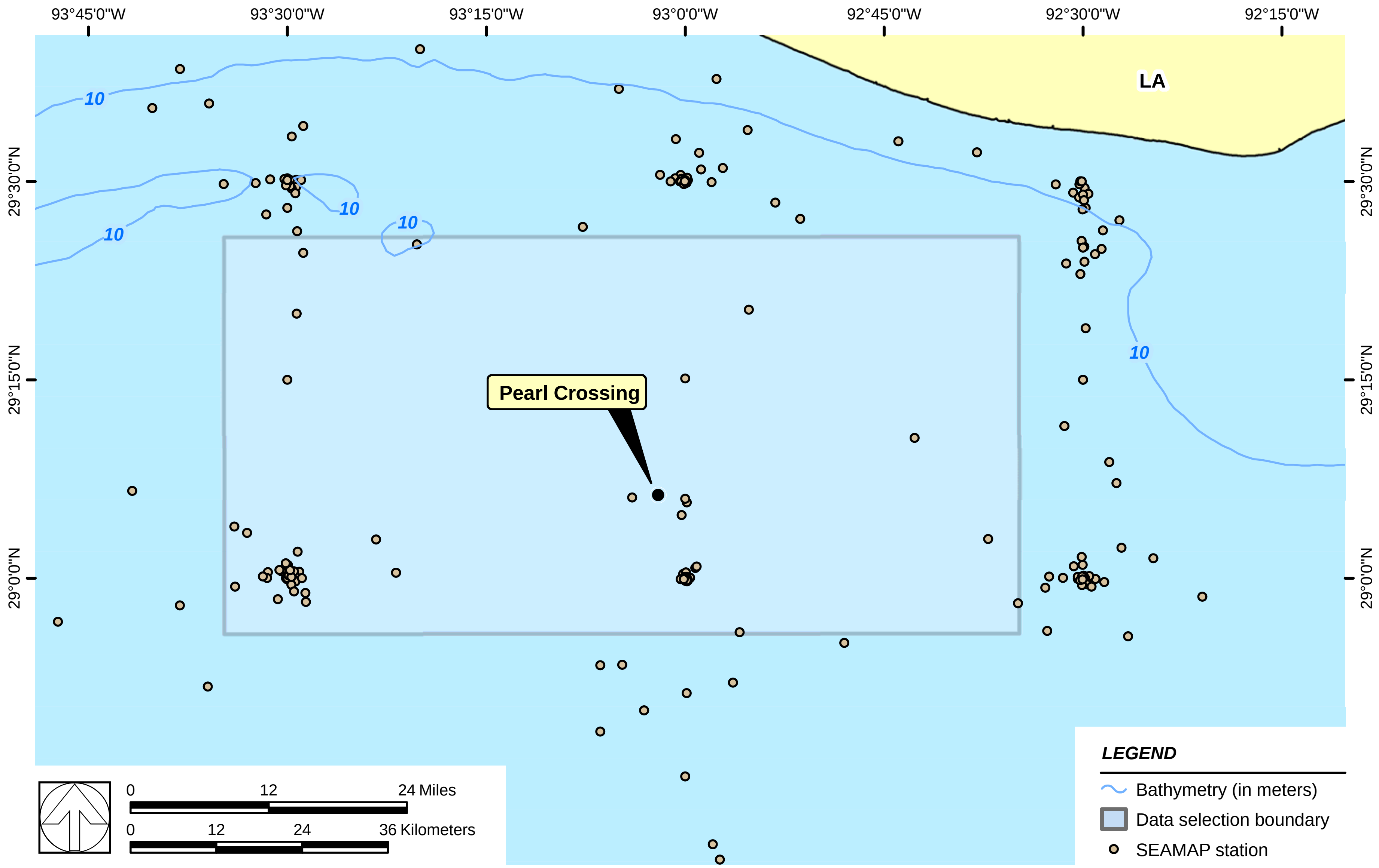


Note: Data are from all years.

Source: NOAA's National Coastal Data Development Center

Figure 3-3. Main Pass facility with SEAMAP stations



Note: Data are from all years.

Source: NOAA's National Coastal Data Development Center

Figure 3-4. Pearl Crossing facility with SEAMAP stations

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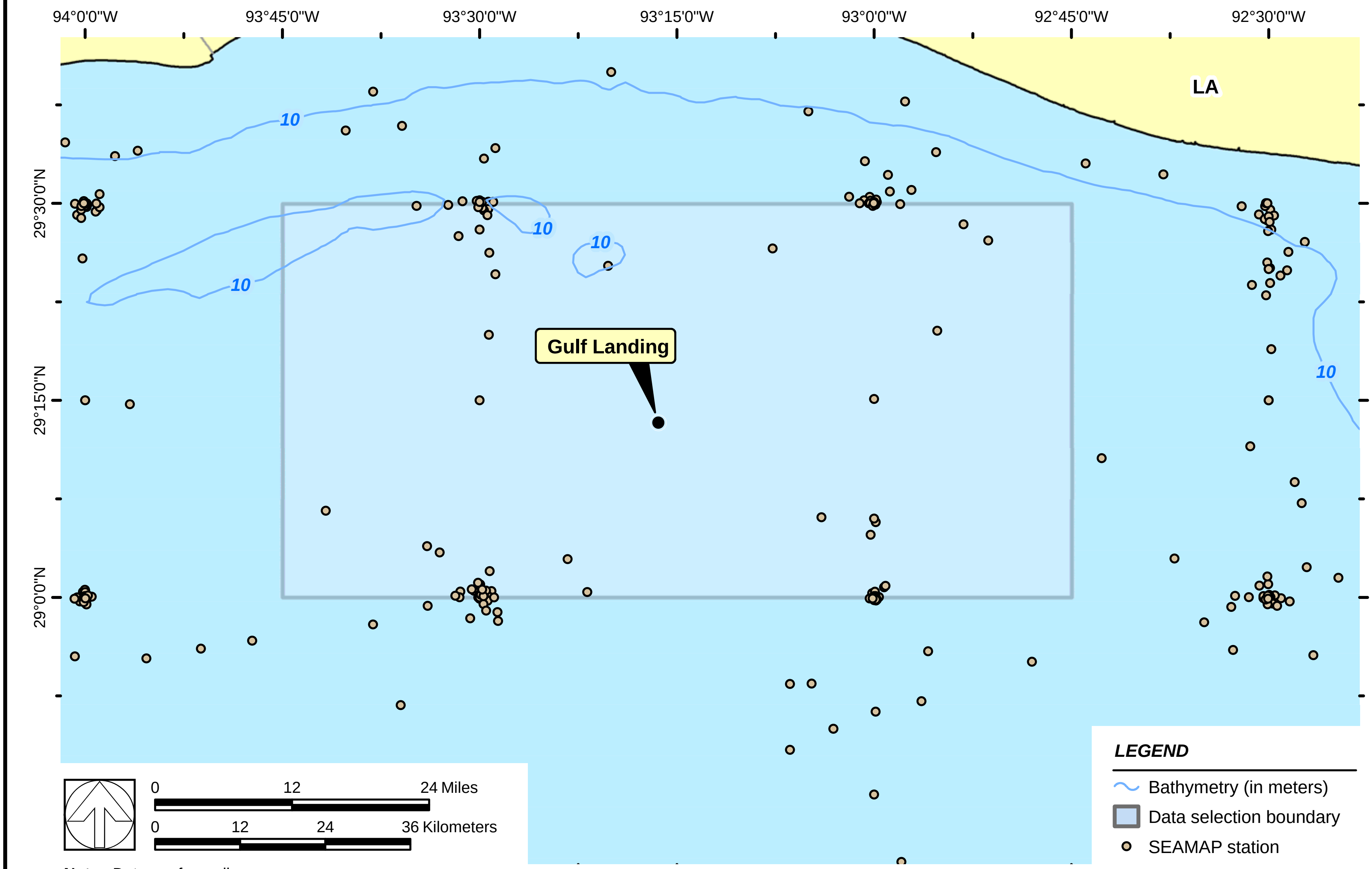

Note: Data are from all years.

Source: NOAA's National Coastal Data Development Center

Figure 3-5. Gulf Landing facility with SEAMAP stations

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BN02922.001 0101 | September 22, 2005 | M:\BN02922_LNG\projects\Figure3-5.mxd potential for bias of the predicted impacts. Several of these limitations are discussed in the following sections, with a focus on their potential effect on impact assessments.

3.1.1 Vertical Distributions of Ichthyoplankton

For planktonic organisms such as fish larvae, the waters of the ocean are not a uniform habitat, but one that is characterized by gradients of light, temperature, salinity, and abundance of other species, both predators and prey. Some of these gradients are steepest in the vertical direction (i.e., with depth). The limited swimming abilities of ichthyoplankton species allow them to control their position within these gradients to some degree, and as a consequence, the highest abundance of some organisms may be frequently found within specific depth ranges. The depth preferences of different species may vary, and the depth preference of a single species may vary over time or with age. For example, one study found that red drum larvae in the GOM are typically near the water surface (in the top meter or two) during the daytime, but in deeper water (5 to 12 m) at night (Lyczkowski-Shultz and Steen 1991). Another study found that red drum larvae in an estuarine environment avoided the surface during the day (Holt and Holt 2000), indicating that depth distributions can also vary with habitat or local physical conditions.

Because of the depth stratification of larvae, the depth of the seawater intake for an OLV facility is an important design consideration and such intakes can potentially be located so as to exclude some species of larvae, or some fraction of the total population of larvae, thus reducing entrainment mortalities. For example, a species that migrates vertically, such as red drum, may be at the depth of the seawater intake for only a portion of each day, and this limited exposure could substantially reduce entrainment losses. Although information on depth preferences that is reported in the literature may be used to estimate limitations on exposure for some species, such information is not available in the SEAMAP database. Ichthyoplankton samples collected by the SEAMAP program were collected obliquely over the entire water column: plankton nets were hauled at an angle from just above the sediment to the water's surface. Thus, the data set most relevant for assessing potential entrainment losses does not contain detail on depth distributions of ichthyoplankton.

The consequence of this limitation is that entrainment estimates for several species, and thus also for ichthyoplankton as a whole, are likely to be overestimates. This limitation is acknowledged in the EISs, but neither the EISs nor comments by NOAA/NMFS have attempted to quantify or bound the magnitude of this overestimation. Accurately quantifying the degree of overestimation cannot be done without an in-depth analysis of data on the vertical distribution of individual species. The EISs assume that larvae are uniformly distributed throughout the water column, and relative to this assumption, larvae may be more or less exposed to entrainment depending on the depth preference of the species and the depth of the seawater intake. If red drum's migratory behavior is treated as an archetype, or if the middle of the overall range of effects is taken, it appears that entrainment could be reduced by on the order of 50 percent by appropriate location of the seawater intake. This factor illustrates the order of magnitude by which current entrainment predictions may be overestimated. That is, predictions may be overestimated by integer factors rather than by just a few percent.

If a detailed review of all available literature data on depth distributions of ichthyoplankton in the GOM were to reveal that most species showed distinct depth preferences, then some generalization to ichthyoplankton as a whole may be warranted. Alternatively, entrainment estimates for individual species, such as red drum, could be modified to account for current best estimates of larval depth distributions in the locations of the seawater intakes. The alternative is to recognize that entrainment estimates are likely to be biased high, but by an unknown amount.

3.1.2 Temporal Coverage

SEAMAP has collected data in most months of the year, although sampling intensity has been greatest during the period of April through November. Because most fish spawn in the spring, summer, or fall, this period should include most of the egg and larval production in the GOM. However, at any single sampling location, the number of months sampled may be very limited, despite the entire 21 years of data collection. Thus, despite the comprehensiveness of the overall data set, the information available in the vicinity of a proposed OLV facility may be substantially more limited. This is illustrated by the case of the Gulf Landing facility, for which there are 96 SEAMAP samples within the area of potential influence, but those samples represent only the months of August through November.

Because there are large month-to-month variations in the abundance of larvae of individual species as a result of seasonal spawning, it is not generally appropriate to assume that larval abundance in unmeasured months are similar to those in measured months. For species with well-known life histories, there can be a legitimate basis for assuming certain abundance in unmeasured months (e.g., based on abundance in measured months). For species without well-known life histories, and for the mass of ichthyoplankton as a whole, months with missing data may add substantial uncertainty to estimates of annual entrainment. Quantifying the uncertainty as well as possible, for as many individual species as possible, should reduce the uncertainty for the remainder of the ichthyoplankton for which no life history information is available. When temporal coverage is incomplete, the range of uncertainty for species with known life history information may be an appropriate guide to the relative uncertainty in the remainder of the ichthyoplankton data. Such uncertainty analyses would be appropriate for the SEAMAP data set, but have not been considered in the EISs or in the comments.

3.1.3 Spatial Coverage

SEAMAP samples were collected throughout the GOM, and therefore nominally cover all of the areas of existing and proposed LNG terminals. However, this coverage is not uniform. Most SEAMAP samples, particularly in the western Gulf, are located at or near 30-minute intervals of latitude and longitude (Figure 3-1). In some cases (e.g., Gulf Landing and Pearl Crossing) the consequence is that although SEAMAP data have been collected north, south, east, and west of the facility, most of those data are relatively distant from the facility itself. Because of variability in spawning areas and ichthyoplankton abundance throughout the northern GOM, data that are distant from a facility may have limited relevance. For example, Figure 3-6 shows the variations in abundance with distance from shore in the region of the Gulf Landing facility

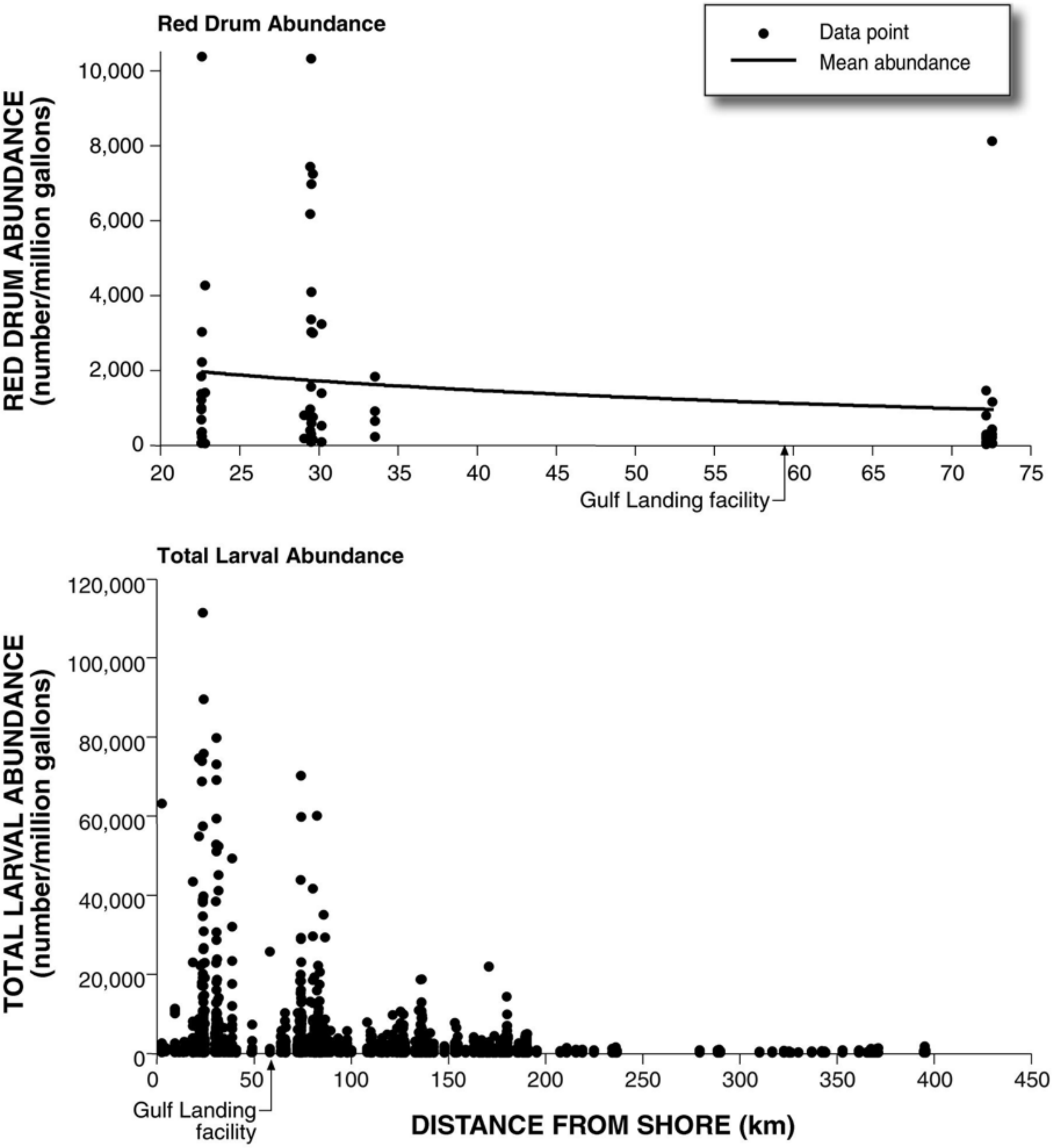

Figure 3-6.
Larval abundance with distance from shore in the vicinity of the Gulf Landing facility (SEAMAP data from all years)

for both red drum and all ichthyoplankton larvae. SEAMAP stations that are to the north of the Gulf Landing facility have systematically higher abundance of red drum larvae than SEAMAP stations to the south. In cases like this, the uncertainty of predicted larval abundance at the facility would be higher than if only data close to the facility itself were used for the assessment.

3.1.4 Taxonomic Detail

Not all of the larvae captured in SEAMAP collections could be identified to the level of an individual species. Larvae with ambiguous identities are therefore identified only to the level of the genus, family, or order. Ambiguous taxonomy poses a challenge for evaluations of potential species-level impacts, because an indeterminate number of individuals of the species of concern may be identified only to a higher taxonomic level. One way to address this uncertainty is to allocate the individuals at a higher taxonomic level (e.g., genus) to the species within that genus, in proportion to the number of individuals positively identified within that species. For example, if there are two species within a genus, and the first of these makes up 80 percent of all individuals identified to the species level, and the other one makes up 20 percent of all individuals identified to the species level, then the individuals that were identified only to the genus level would be allocated in the proportion of 80:20 between the two species.

This approach assumes that some individuals of all species present can be identified to the species level, and that the inability to identify an organism to the species level is a random process—that is, it does not occur more frequently for one species than another. These assumptions are necessary, but are of unknown accuracy. Consequently, they increase the uncertainty of abundance estimates but do not necessarily impose either a positive or a negative bias on the estimate.

The general approach described above has been applied in most of the EISs for OLV facilities (except for the Beacon Port facility[5]). However, the technique has been applied inappropriately to the overall ichthyoplankton collection, whereas it should be applied only to individual samples. The ichthyoplankton modeling appendix in the EIS for the Gulf Landing facility (e2M 2005) describes the way that this technique has been applied to the overall collection. Applying the technique in this way is inappropriate because there are systematic seasonal variations in abundance of individual species. Specifically, larvae of some species may be completely absent at some times, while at the same time there are other species that have been identified only to higher taxonomic levels. Assuming that some of the organisms identified only to higher taxonomic levels actually belong to a species that spawns at a completely different time of year will erroneously inflate the estimated abundance of that species. The systematic seasonal variations in species abundance can be taken into account so that they do not inflate the uncertainty of the abundance estimate.

The contrast between making the correction for ambiguous taxonomy for the overall collection versus making it for individual samples can be illustrated using the red drum data for the Gulf Landing facility. For this facility, ichthyoplankton data were available for the period of July through November, for several years. Red drum larvae were found to be present only in September, with one observation in October. However, individuals identified only to the level of the family Sciaenidae (which includes red drum) were found in all months. Interpreting a fraction of all organisms identified as Sciaenidae to be red drum, without regard to date, would skew both the abundance and the seasonal distribution of the resulting estimates of red drum.

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[5] The Beacon Port application assumed that *all* larvae identified only to a higher taxonomic level belonged to each species of concern that belonged in that taxonomic category. This technique represents a worst-case condition, and is likely to substantially overpredict larval abundance, and thus entrainment losses.

This consideration applies to all species. Consequently, adjusting the abundance of individual species based on proportional allocation of ambiguously identified taxa should only be done on a sample-specific basis. Making the adjustment in this way will result in more accurate (generally lower) and more precise estimates of abundance.

As noted previously, no taxonomic identification has been done of ichthyoplankton eggs in the SEAMAP collection. As a consequence, there is no concrete information about egg abundance of individual species. The abundance of eggs of each species can be assumed to be proportional to the abundance of larvae of each species, and this approach has been used in the EISs. However, this approach further assumes that all species have identical instantaneous mortality rates and stage durations of both eggs and larvae, which are inappropriate assumptions. Thus, the taxonomic ambiguity of the SEAMAP egg data limits the usability of these data, resulting in an increase in the uncertainty of species-specific egg abundance estimates, and in potential entrainment impacts. The usability of the SEAMAP egg data is further limited because of considerations of net capture efficiency, as discussed in the following section on modeling. An alternative approach to calculation of egg abundance is also presented there, and that approach eliminates the problems stemming from both taxonomic ambiguity of eggs and unknown net efficiency for eggs.

3.2 Abundance Calculations and Population Impact Modeling

Species-specific estimates of potential impacts from entrainment of fish eggs and larvae have been made using the SEAMAP data in a multi-step process (Figure 3-7). This process, as used in the OLV facility EIS, has two major components: 1) estimation of egg and larval abundance, and 2) estimation of the number and weight of fish at harvestable ages. Species-specific estimates of egg and larval abundance are made using the actual measured abundance of larval fish of the species of interest, combined with data on abundance of fish at higher taxonomic levels, abundance of all larval fish, and abundance of eggs of all species. Assumptions about proportional equivalence of different species, and of eggs and larvae, are incorporated into these calculations. The second major component of the assessment of potential population impacts is the projection from egg and larval abundance to abundance of adult fish at different ages. These calculations rely on a population model that is driven by assumptions about age-specific mortality rates and life stage durations.

The approaches taken to both the abundance calculations and the population impact modeling have weaknesses that affect both the accuracy and the precision (i.e., uncertainty) of the predictions. The approaches used in the EIS, limitations of these approaches (i.e., uncertainty and bias), and recommended alternatives are described in the following sections.

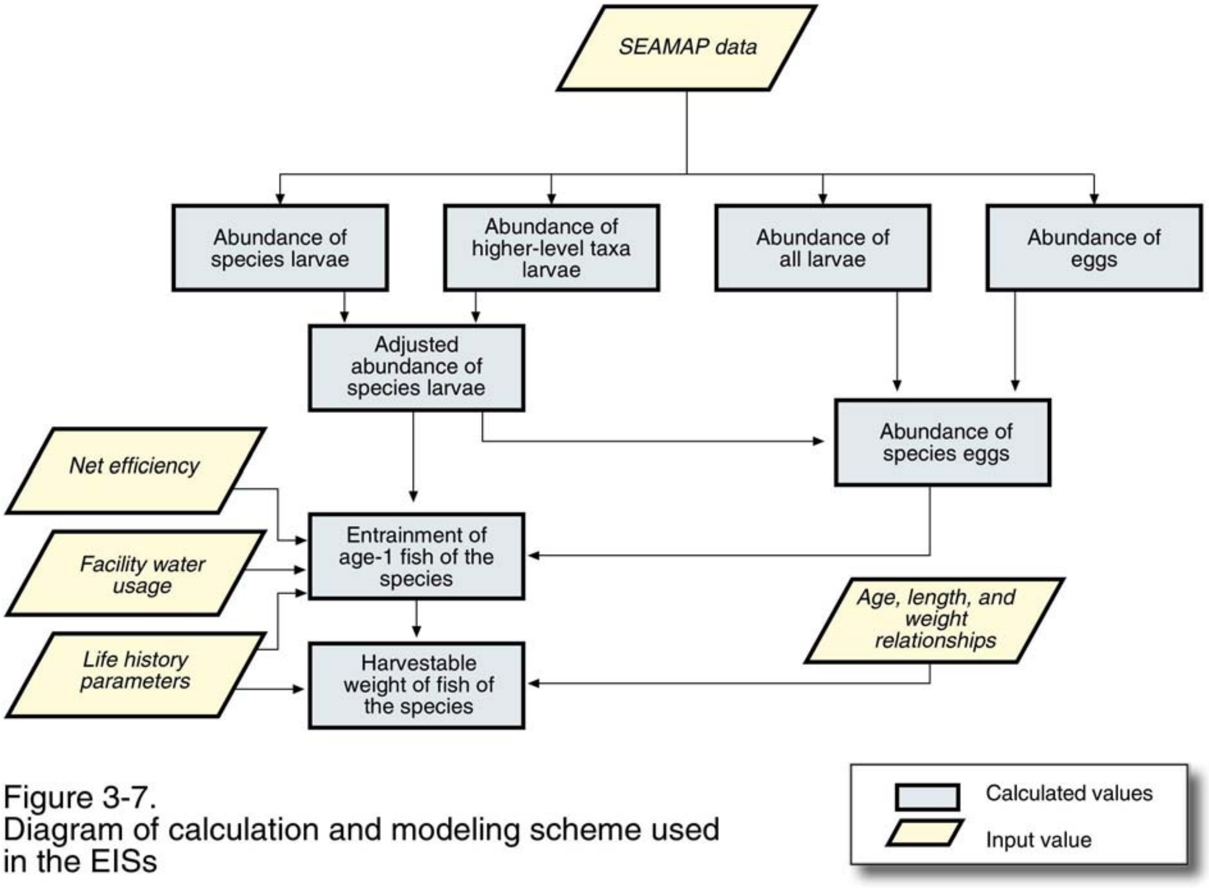

Figure 3-7.
Diagram of calculation and modeling scheme used in the EISs

3.2.1 Calculation of Larval Abundance

Calculation of the abundance of fish larvae near OLV facilities is the foundation on which the impact assessments are based. The EISs calculate entrainment from fish larval abundance, as estimated from SEAMAP data, and then project these values forward to estimate fishery yield. The EISs also estimate the egg abundance of each species from larval abundance. Larval abundance therefore should be calculated in the most accurate and precise way possible.

There are two factors that can strongly affect both the magnitude and the variability of estimates of larval abundance. These are the fraction of total larvae captured by the sampling gear (net efficiency) and the treatment of systematic seasonal variations in plankton abundance. Net efficiency has not been measured for the SEAMAP data set, yet some value must be used to carry out the calculation of larval abundance. Variations in net efficiency translate directly into variations in abundance estimates. Systematic variations in plankton abundance result from seasonal spawning behavior. These variations, if not properly accounted for, result in overestimates of the uncertainty of abundance estimates.

3.2.1.1 Net Efficiency

Plankton nets ordinarily do not capture all of the plankton in their path, and thus are not 100 percent efficient. The proportion of all plankton that is actually retained by the net is referred to as the net efficiency. Net efficiency can be decreased by several factors, including:

- Loss of organisms through the net mesh. A substantial fraction of eggs and larvae that are smaller than the net mesh are likely to pass through. Distortion of the net fabric can allow some organisms that are nominally larger than the net mesh size to also pass through.
- Active avoidance. More mobile members of the ichthyoplankton may be capable of moving out of the way of the net. Organisms near the outer edge of the net's circumference need only move a relatively small distance to escape capture.
- Diversion by a pressure head at the net mouth. The net mesh resists water passage, and as a result, a pressure head builds up in front of the net. This pressure head diverts some water that is in the path of the net, and may also provide a cue for organisms that are capable of avoidance behavior.

The combined effect of these factors may be to substantially affect the data on egg and larval abundance. Houde and Lovdal (1984) found ichthyoplankton abundance in Biscayne Bay to be 5–8 times higher when assessed with a net with a 35 μm mesh than with a net with a 333 μm mesh. A study by Comyns (1997) in the north-central GOM found larvae to be five times more abundant in 202 μm mesh net compared to the 333 μm mesh. These studies indicate that a 333 μm net is about 13 to 20 percent efficient relative to the 35 μm net, and about 20 percent efficient relative to a 202 μm net. The 35 μm and 202 μm nets themselves, however, are not likely to have been 100 percent efficient. SEAMAP collections were made with a 333 μm net, and so are likely to be substantially less than 100 percent efficient.

Net efficiency is not easy to measure or estimate. SEAMAP uses flow meters in the nets, which should effectively compensate for most of the effects of water diversion at the net mouth. Pass-through and avoidance, however, are still likely to reduce net efficiency in the SEAMAP. In fact, net efficiency will vary from species to species, and will also vary with the form and size of individuals within a species. EISs for the OLV facilities have used a net efficiency value of 33 percent at the recommendation of the NMFS Southeast Fisheries Science Center (NMFS 2004). The quantitative basis of this value is unknown. The consequence of uncertainty about the actual net efficiency is that actual ichthyoplankton abundance could differ from estimated abundance by factors that may be on the order of two or three.

The same net efficiency value has been used for both eggs and larvae in the OLV EISs. Realistically, different net efficiencies are to be expected for eggs and larvae. Eggs can be expected to have lower net efficiencies than larvae because eggs are smaller and because they always present their smallest dimension to the net. The use of the same net efficiency value for both is therefore likely to be inappropriate. However, the SEAMAP data set provides no way to either directly estimate the absolute net efficiency for eggs and larvae or the relative net efficiency for eggs compared to that for larvae. Consequently, the egg abundance and entrainment estimates in the EISs are most likely underestimates (assuming that the net efficiency value used is appropriate for larvae). This problem could be addressed using estimates of net efficiency for eggs produced by other studies, although the applicability of such studies may be limited to certain species.

Another and preferred approach would be to estimate egg abundance using the measured larval abundance and available mortality rates for both eggs and larvae. This approach eliminates the need to use the SEAMAP egg data, which is of limited value because of the unknown net efficiency and the taxonomic ambiguity. This recommended approach—estimating egg abundance from larval abundance—is, however, limited to just those species for which mortality rates are available. The technique should be applicable to all commercially important species for which stock assessments have been performed. Monitoring programs for permitted facilities can also be designed to provide data to address this and other uncertain factors.

3.2.1.2 Seasonality and Variability

Seasonal spawning results in high variability in larval abundance from month to month, and even from day to day throughout the spawning period. This is regular, systematic, natural variability, in contrast to the effectively random sampling variability that results from differences in gear performance, plankton patchiness, and taxonomist expertise. The quantity of SEAMAP data available allows the variability resulting from seasonal spawning to be assessed—and this variability should be assessed to avoid overestimating the uncertainty in plankton abundance and yearly entrainment estimates. The EISs ignore seasonality, and as a consequence, significantly overestimate the variability (and uncertainty) of estimated larval abundance. For example, in a sequential series of five larval abundance measurements, the first may have no larvae, the second a low number, the third a high number, the fourth a low number, and the fifth none. The overall variability of this sequence of measurements is high, but each individual measurement may be quite precise. The sum of these individual abundance estimates (i.e., potential entrainment) can also be relatively precise. EISs for the OLV facilities applied the overall variability to the entrainment estimate, without regard to systematic variation. The consequence of this calculation is that larval abundance and entrainment estimates in the EISs have a substantially higher estimate of variability than would be obtained by propagating the uncertainty of the individual measurements.

Systematic seasonal variability of larval abundance is apparent in the SEAMAP data. Figure 3-8 shows the data for red drum larval abundance in the vicinity of the Gulf Landing facility, for the period of September-October. Data for all years are combined in this figure. The sequence of increasing abundance followed by decreasing abundance throughout this period is clearly evident. Red drum larvae are completely absent at other times of the year. Within the period of high abundance there are also observations of low abundance, which is likely attributable to the patchy nature of plankton populations. The approach taken in the EISs lumped all these data together to calculate a single average abundance and variability estimate. Using this approach, the estimated variability was quite high. However, there is a better approach: by averaging successive measurements over time periods that are short relative to the overall variation, the effects of this patchiness can be smoothed out to achieve a more representative long-term average larval abundance for the period. Grouping of data over short periods also allows the variability, or precision, of each average abundance to be estimated. Figure 3-8 also shows the result of computing an 11-day moving average over the period of red drum larval abundance. The systematic nature of the variability is even clearer in this figure. Other averaging techniques, such as grouping successive sets of at least five measurements, produce similar results. Treating data in this way allows the calculation of a much more precise estimate of potential entrainment losses than does the approach used in the EISs.

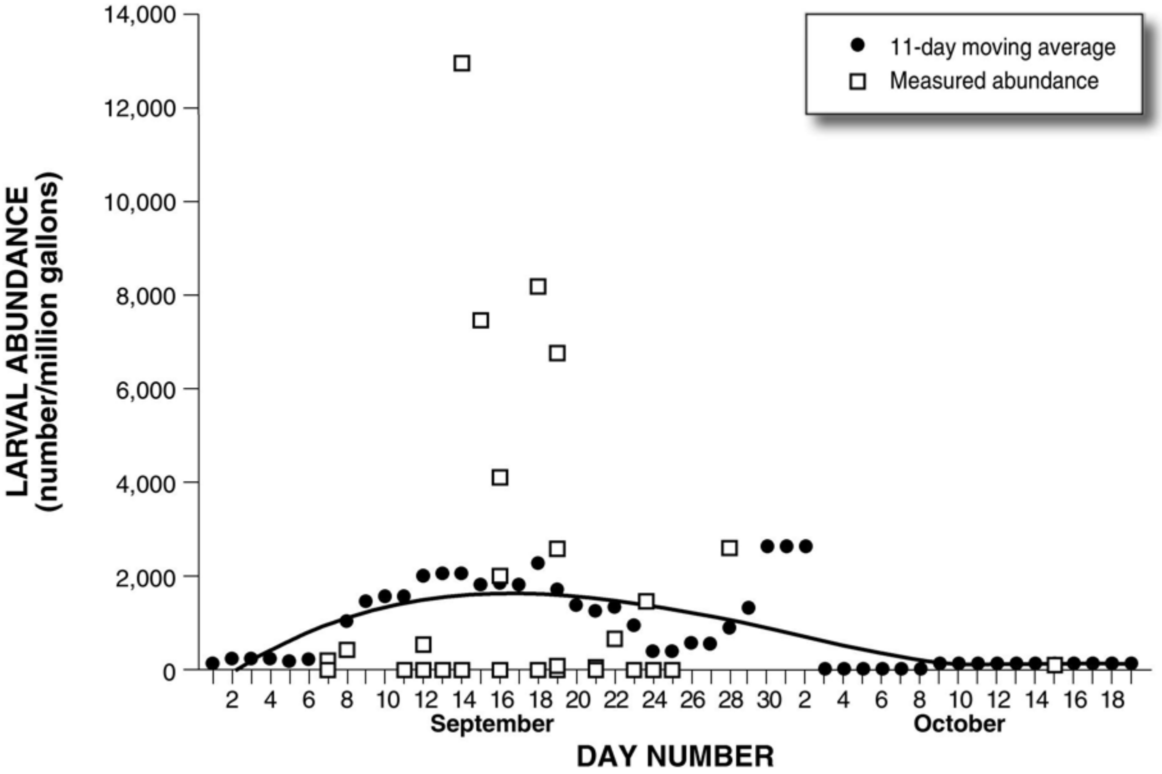

Figure 3-8.
Red drum larval abundance during September and October in the vicinity of the Gulf Landing facility

3.2.1.3 Recommended Approach to Calculation of Larval Abundance

Several of the factors discussed previously can be addressed in a way that produces estimates of fish larval abundance that are both more accurate and more precise than the estimates in the EISs. The elements of this alternative, and recommended, approach to computing larval abundance are as follows:

- Compute abundance separately for each species of concern
- Correct for taxonomic ambiguity on a sample-specific basis

- Account for seasonality in an appropriate manner that does not inflate uncertainty
- Combine data across years and group successive measurements to allow daily estimates of abundance, and the associated variance
- Sum the daily abundance estimates, and propagate the variance, to produce an estimate of potential annual entrainment.

This approach, and its results, can be illustrated using data for red drum in the vicinity of the Gulf Landing facility. To perform this calculation, SEAMAP data were selected in the manner described in the EIS (e2M 2005), and confirmed to produce the same values shown in Table G-5 of that document. The total number of red drum larvae in each sample was adjusted upward, if appropriate, by multiplying the proportion of red drum within all taxa in the family Sciaenidae by the number of taxa identified only to the level of the family Sciaenidae. The resulting abundance values (in terms of larvae per million gallons) were converted to estimated daily entrainment values by multiplying by 3 to account for net efficiency and by 136 to account for the daily seawater intake of the Gulf Landing facility. These data are shown in Table 3-1.

An estimate of red drum larval entrainment was then calculated for each day of the period when red drum are present. Daily means and the variance of those means were computed using an 11-day moving average—that is, the estimate for each day incorporated all data up to 5 days earlier or later, regardless of year. Means and variances were then summed across all days to determine total potential entrainment and the variance of that total.[6] Upper and lower 95 percent confidence limits were then calculated for the total. The results of these calculations are shown in Table 3-2.

This approach to calculating larval abundance produces an estimate of approximately 16 million red drum larvae entrained annually by the Gulf Landing facility, with 95 percent confidence limits ranging from 13 million to 19 million. In contrast, the calculation approach used in the Gulf Landing EIS (e2M 2005) produced an estimated total of approximately 36 million larvae entrained annually, with 95 percent confidence limits ranging from 3 million to 69 million (Table G-11 of e2M [2005]). Performing the correction for ambiguous taxonomy on a sample-specific basis results in a lower estimated total, and properly distinguishing seasonal variability from uncertainty results in far narrower confidence limits. The result is a more accurate and precise estimate that is a better basis for decision making. The revised calculation approach should be applied to all species of concern.

3.2.2 Entrainment Mortality

The facility EISs have assumed that there will be a 100 percent mortality of all fish eggs and larvae entrained in the OLV system. This assumption appears to be based on a conservative approach resulting from an absence of specific information concerning entrainment mortalities

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[6] The variance of a sum is equal to the sum of the variances of the summands (Bevington and Robinson 1992).

Table 3-1. Red drum larval abundance at the Gulf Landing facility (SEAMAP data)

Sampling Date	Day Number	Measured Red Drum Abundance[a]	Adjusted Total Abundance of Red Drum[a,b]	Estimated Daily Entrainment of Red Drum Larvae[c]
09/05/01	248	205	205	83,483
09/05/01	248	0	0	0
09/06/01	249	386	428	174,634
09/09/99	252	0	0	0
09/10/91	253	0	0	0
09/10/96	253	541	541	220,635
09/11/91	254	0	0	0
09/11/92	254	0	0	0
09/11/92	254	0	0	0
09/11/92	254	0	0	0
09/11/96	254	0	0	0
09/11/97	254	0	0	0
09/12/97	255	10,305	13,013	5,309,299
09/12/97	255	0	0	0
09/13/95	256	7,227	7,505	3,061,886
09/14/95	257	0	0	0
09/14/00	257	4,088	4,130	1,684,847
09/14/00	257	1,236	2,015	822,091
09/16/94	259	6,169	8,225	3,355,827
09/16/94	259	0	0	0
09/17/86	260	3,028	6,786	2,768,557
09/17/86	260	0	0	0
09/17/93	260	0	0	0
09/17/94	260	69	92	37,441
09/17/94	260	1,487	2,598	1,060,061
09/19/02	262	50	50	20,593
09/19/02	262	0	0	0
09/19/02	262	0	0	0
09/20/02	263	665	665	271,321
09/21/87	264	0	0	0
09/21/88	264	0	0	0
09/22/87	265	0	0	0
09/23/90	266	0	0	0
09/26/88	269	968	2,610	1,065,026
10/13/98	286	76	98	39,785

[a] Number per million gallons.

[b] Adjusted for the number of individuals identified only to the family Sciaenidae.

[c] Calculated from abundance using a factor of 3 for net efficiency, and by a factor of 136 (MGD) for OLV throughput.

Table 3-2. Mean and confidence limits of annual red drum larval entrainment by the Gulf Landing facility[a]

Calendar Date	Day Number	First Day of 11-day Window	Last Day of 11-day Window	Mean Abundance over the Window	N	Variance of the Mean	Running Sum of Mean Larval Abundance	Running Sum of Variance
08/31	243	238	248	41,742	2	1,742,370,196	41,742	1,742,370,196
09/01	244	239	249	86,039	3	2,543,042,881	127,781	4,285,413,076
09/02	245	240	250	86,039	3	2,543,042,881	213,820	6,828,455,957
09/03	246	241	251	86,039	3	2,543,042,881	299,859	9,371,498,837
09/04	247	242	252	64,529	4	1,734,191,119	364,388	11,105,689,956
09/05	248	243	253	79,792	6	1,598,184,607	444,180	12,703,874,563
09/06	249	244	254	39,896	12	507,922,840	484,076	13,211,797,403
09/07	250	245	255	413,432	14	142,207,860,093	897,508	1.5542E+11
09/08	251	246	256	589,996	15	154,421,504,621	1,487,504	3.09841E+11
09/09	252	247	257	630,937	18	111,107,865,112	2,118,441	4.20949E+11
09/10	253	248	258	630,937	18	111,107,865,112	2,749,379	5.32057E+11
09/11	254	249	259	812,734	18	132,449,094,882	3,562,113	6.64506E+11
09/12	255	250	260	832,757	22	99,398,267,304	4,394,870	7.63904E+11
09/13	256	251	261	832,757	22	99,398,267,304	5,227,626	8.63303E+11
09/14	257	252	262	733,649	25	79,538,368,980	5,961,276	9.42841E+11
09/15	258	253	263	744,502	25	78,992,637,935	6,705,778	1.02183E+12
09/16	259	254	264	735,677	25	79,455,803,389	7,441,455	1.10129E+12
09/17	260	255	265	919,596	20	116,554,878,280	8,361,051	1.21784E+12
09/18	261	256	266	688,559	19	70,196,442,706	9,049,610	1.28804E+12
09/19	262	257	267	556,708	18	59,024,765,724	9,606,318	1.34707E+12
09/20	263	258	268	500,920	15	70,829,718,869	10,107,238	1.4179E+12
09/21	264	259	269	536,177	16	69,417,377,360	10,643,415	1.48731E+12
09/22	265	260	270	373,071	14	44,229,720,846	11,016,486	1.53154E+12
09/23	266	261	271	150,771	9	13,940,715,084	11,167,257	1.54548E+12
09/24	267	262	272	150,771	9	13,940,715,084	11,318,028	1.55942E+12
09/25	268	263	273	222,724	6	30,341,916,302	11,540,752	1.58977E+12
09/26	269	264	274	213,005	5	45,371,176,322	11,753,758	1.63514E+12
09/27	270	265	275	355,009	3	126,031,045,338	12,108,766	1.76117E+12
09/28	271	266	276	532,513	2	283,569,852,011	12,641,279	2.04474E+12
09/29	272	267	277	1,065,026		0	13,706,304	2.04474E+12
09/30	273	268	278	1,065,026		0	14,771,330	2.04474E+12
10/01	274	269	279	1,065,026		0	15,836,356	2.04474E+12
10/02	275	270	280	0		0	15,836,356	2.04474E+12
10/03	276	271	281	0		0	15,836,356	2.04474E+12
10/04	277	272	282	0		0	15,836,356	2.04474E+12
10/05	278	273	283	0		0	15,836,356	2.04474E+12
10/06	279	274	284	0		0	15,836,356	2.04474E+12
10/07	280	275	285	0		0	15,836,356	2.04474E+12
10/08	281	276	286	39,785		0	15,876,140	2.04474E+12
10/09	282	277	287	39,785		0	15,915,925	2.04474E+12
10/10	283	278	288	39,785		0	15,955,710	2.04474E+12
10/11	284	279	289	39,785		0	15,995,495	2.04474E+12
10/12	285	280	290	39,785		0	16,035,280	2.04474E+12
10/13	286	281	291	39,785		0	16,075,065	2.04474E+12
10/14	287	282	292	39,785		0	16,114,850	2.04474E+12
10/15	288	283	293	39,785		0	16,154,634	2.04474E+12
10/16	289	284	294	39,785		0	16,194,419	2.04474E+12
10/17	290	285	295	39,785		0	16,234,204	2.04474E+12
10/18	291	286	296	39,785		0	16,273,989	2.04474E+12
				Total number of larvae:			16,273,989	
				Standard deviation of the total:			1,429,943	
				Lower 95% confidence limit:			13,471,300	
				Upper 95% confidence limit:			19,076,678	

[a] See Table 3-1 for the original data used in this calculation.

of GOM species in systems involving drops in temperatures and chlorination to prevent biofouling. In characterizing any predicted risks, such assumptions may result in overestimates of ELS mortalities for fishes. Therefore, the bottom-line predictions in the risk assessment should include a qualification relating to all conservative assumptions that may result in an overestimate of actual entrainment mortalities. The determination of more accurate estimates of the possible survival of entrained eggs and larvae would require monitoring of an existing facility, possibly supplemented by laboratory or simulator studies.

Experience at operating power plants with once-through cooling water systems has shown that mortalities of entrained fish eggs and larvae may be substantially less than 100 percent (Mayhew et al. 2000; U.S. EPA 2002). These assessments have shown that entrainment mortality rates for fish eggs and larvae are highly dependent on species, life stage, plant operating characteristics, and discharge temperature. However, in many cases, individual survival rates for entrained ichthyoplankton have been documented at 20 to >90 percent.

Although there are many uncertainties associated with these studies, including the potential for latent mortalities not documented in the relatively short-term observations, it is clear that actual mortality rates may be well less than 100 percent. Notably, however, all of the studies at power plants involved increases in temperatures and there is little information concerning the effects of chlorination during the field assessments.

Entrainment mortality may also be reduced by active avoidance of the seawater intake by ichthyoplankton. The numbers of larvae entrained by both screened and open intakes at a flow velocity of 0.15 m/s (0.5 ft/s) was as little as 10 percent of ambient abundance (Zeitoun et al. 1981). In contrast, egg abundance was similar, indicating that fish larvae were actively avoiding the intake. The intake velocity tested by Zeitoun et al. (1981) was similar to that planned for the LNG facilities (USCG and MARAD 2005a).

The assumption of 100 percent entrainment mortality therefore is likely to be inaccurate and will result in an overestimate of potential impacts. The data of Zeitoun et al. (1981) suggest that larval mortality could be overestimated by as much as a factor of 10. The likelihood of an overestimate of larval mortality should be considered when evaluating the predicted effects of the OLV facilities.

3.2.3 Spatial Effects on Mortality

There are two important factors that can cause spatial variations in larval fish mortality in the GOM, and that are therefore relevant to potential mortality at the locations of LNG facilities. These factors are:

- Spawning areas and habitat areas for larval fish
- Hypoxic zones.

Fish species do not all spawn uniformly throughout the GOM, and larvae of different species use different habitats during their maturation period. For example, red drum adults spawn within approximately 20 miles of the shoreline (http://www.ncddc.noaa.gov/website/

CHP/viewer.htm), and red drum larvae eventually settle in estuaries (Holt and Holt 2000). Thus, red drum larvae that are transported out of the spawning area to waters farther away from shore are likely to experience very high mortality rates. Eggs and larvae from coastal spawning fishes such as red drum that are transported offshore may have little viability because juveniles normally remain in protected estuaries. Entrainment of these larvae in offshore LNG facilities may therefore result in no net increase in mortality over the natural mortality rate that would occur. Not all fish have the same spawning areas and larval habitat requirements as red drum, but spatial preferences of one kind or another are common. For many species, at least the commercially important ones, these spatial preferences should be reviewed relative to the locations of individual facilities. Such a review can indicate, at least on a qualitative basis, whether entrainment estimates for the facility may be subject to a positive or negative bias.

Seasonal (midsummer) depressions in dissolved oxygen levels, or hypoxia, have become a regular occurrence in bottom waters of the GOM. Low dissolved oxygen levels can cause avoidance, growth reduction, and mortality of marine life. Although sensitivity to hypoxia varies from species to species, a dissolved oxygen concentration lower than 5 mg/L is commonly considered the region of biological avoidance or impairment. Figure 3-9 shows recent data for minimum dissolved oxygen concentrations in waters of the GOM, relative to locations of the LNG facilities. Several facilities are located within the area of seasonal hypoxia. Fish eggs and larvae collected in these locations during midsummer may be subject to elevated mortality rates resulting from the hypoxic conditions. The oblique net tows taken by SEAMAP start at the bottom of the water column. Consequently, a fraction of the organisms collected are likely to be subject to hypoxic effects. The incremental entrainment mortality at the affected LNG facilities under these conditions is likely to be less than at other locations or at other seasons.

3.2.4 Modeling Approach and Model Endpoints

The adult equivalent yield ichthyoplankton assessment models used in the EISs project measured egg and larval abundance to weights of adult fish, which are then compared to recent Gulf fishery harvests. The steps in this process are as follows:

1. The number of entrained eggs and larvae are estimated using SEAMAP data and several assumptions about entrainment (see Section 3.2.1)
2. The number of equivalent adult (age 1) fish that would be produced from the entrained eggs and larvae are projected using estimates of mortality rates and stage durations
3. The number of fish of harvestable age are projected from the estimated number of age 1 equivalent fish using additional estimates of mortality rates and stage durations
4. The biomass of the fish of harvestable age is estimated using empirical relationships between fish length at age and fish weight versus length
5. The estimated biomass of the fish is then compared to selected fishery landings data.

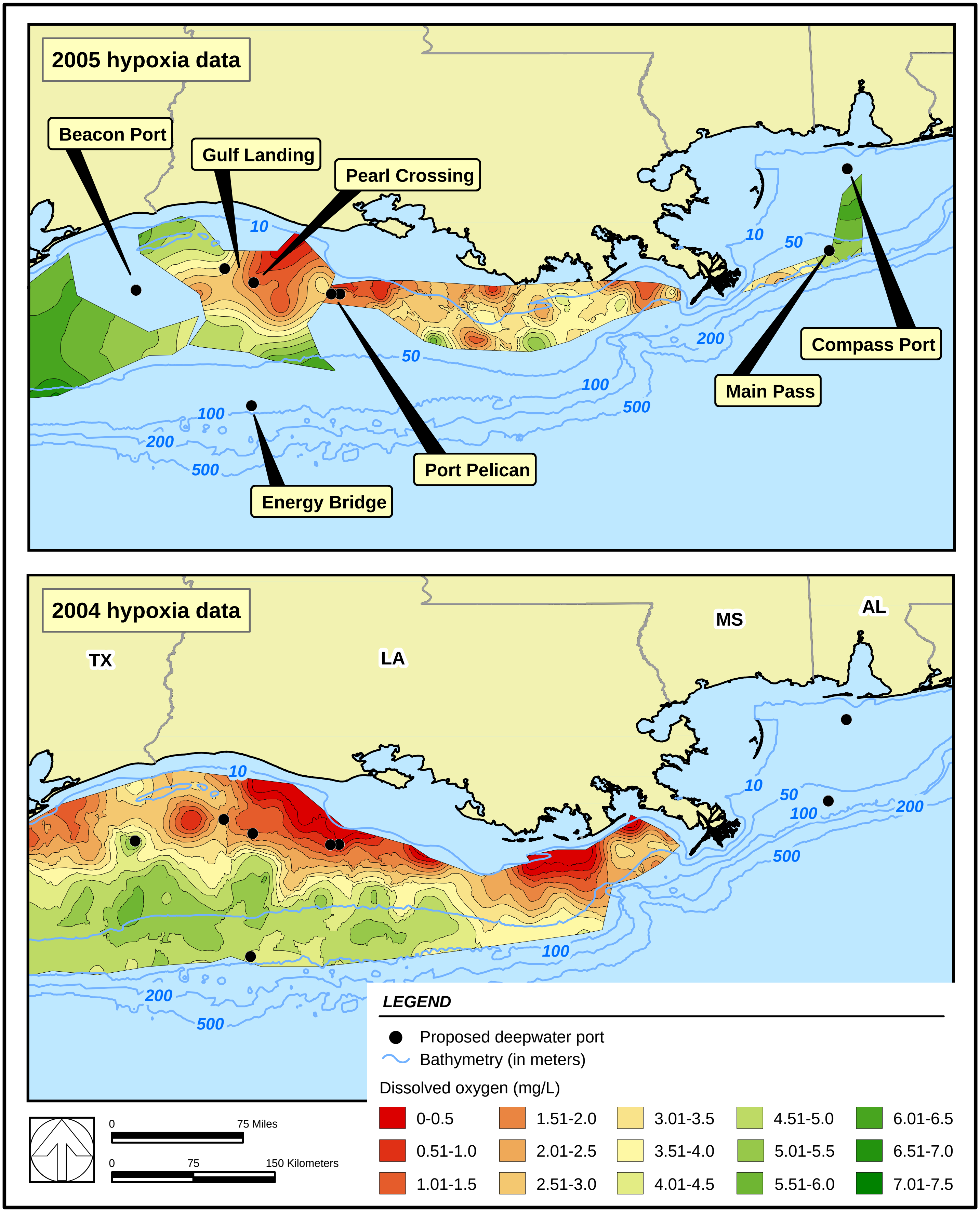

Figure 3-9. Existing and proposed deepwater ports within the GOM with hypoxia contour data

This modeling approach has several weaknesses:

- The projection of egg and larval abundance to abundance and weights of fish of harvestable age requires extensive parameterization, and these parameters are generally poorly known
- The models do not account for density-dependent compensation, which leads to stable populations of adult fish despite variations in egg production and mortality of ELSs
- The comparison to fishery harvest levels does not provide any meaningful information about the potential impacts of OLV facilities on fish populations as a whole
- The model used contains an error in one of its formulas that results in overprediction of egg and larval mortality (Section 3.2.4.4).

These weaknesses lead to a high degree of uncertainty and an overestimate of potential impacts.

In the EISs, the effects of entrainment on the fish population are evaluated by estimating the number of age-1 fish that the entrained eggs and larvae would have grown into had they survived. (An alternative approach, described in Section 3.2.4.5 of this report, is to estimate the number of eggs that were spawned to produce the number of individuals that were entrained.) The projected number of adults is not equal to the number of entrained eggs and larvae because natural mortality reduces the population size as the fish age. Thus, only a small fraction of larvae will naturally survive until adulthood. Correspondingly, only the same fraction of entrained larvae would have survived until adulthood.

Although the actual values are not known with certainty, it is known that natural mortality rates for eggs and larvae are quite high. The natural mortality rate is expressed as the percentage of the population lost per day. For example, the estimated natural mortality rates for red drum eggs and larvae are about 50 percent and 30 percent per day, respectively (Gallaway 2005). (As discussed in Section 3.2.4.1, there is a very high degree of uncertainty associated with estimated mortality rates and life stage durations, so that the corresponding estimates of adult equivalents are also highly uncertain.) The effect of the mortality rate, when it is applied over the entire length of a life stage, is expressed as the survival fraction, which is the number of fish alive at the end of the stage divided by the number alive at the beginning of the stage. For example, the survival fraction for red drum larvae is 0.13 percent (using a mortality rate of 0.3 day^{-1} and a stage length of 22 days). So, for example, if 10,000 red drum eggs were lost due to entrainment, those eggs, had they lived, would have resulted in $10{,}000 \times 0.0013 = 13$ larval red drum. Additional natural mortality in the following juvenile life stages would further reduce the number of those eggs that would have survived to adulthood.

3.2.4.1 Use of Uncertain Life History Parameters in Forward-Projection Models

The use of poorly known life history parameters to project fish abundance through many life stages is responsible for introducing a high degree of uncertainty into the results. Most of the life history parameters are highly uncertain (Barnthouse 2002). This is especially true for marine fish species. Gallaway (2005) evaluated life history parameters for several species and recommended values based on a review of the literature and conversations with original investigators. The resulting values are plausibly the most accurate that are currently available. Nevertheless, the variation in these values is large. For example, the minimum and maximum recommended instantaneous mortality rates for red drum larvae differ by more than a factor of 2. This uncertainty leads to a more than 30-fold difference in the estimated number of larvae surviving throughout the 22-day larval life stage. Other life history parameters, for red drum and other species, also may vary over a range of 30 percent or more, with similarly disproportionate impacts on the estimates of numbers of fish surviving. Compounding this uncertainty throughout numerous life stages results in estimates that have such wide bounds of uncertainty that they should be used with caution and a firm understanding of the biases and uncertainties introduced.

EPRI (2004), which is the source cited by the Gulf Landing EIS and others for the adult-equivalent model used, explicitly recommends against the use of forward-projection models when entrainment mortality primarily affects egg and larval stages. This recommendation is based on the fact that forward-projection models are highly sensitive to the life history parameters chosen, and those parameters are highly uncertain.

3.2.4.2 Compensatory Mechanisms of Population Regulation

Compensation refers to the natural regulation of population size through density-dependent growth, reproduction, and mortality (Rose et al. 2001). In fish populations, compensation can occur through increased survival of young fish (including eggs) when populations are low, and decreased survival when populations are high. Compensation may also occur through density-dependent changes in reproductive success, fecundity, or age of first reproduction of adult fish. The mechanisms of density-dependent compensation are generally poorly known, but may include predation and competition for resources. Compensation is an extremely important component of fish population dynamics, for without it, no significant harvest would be sustainable (Rose et al. 2001). The importance of compensatory mechanism on fish populations can vary widely among species, depending on fundamental features of the species’ reproductive strategy (Rose et al. 2001; Winemiller and Dailey 2002).

Density-dependent mechanisms may act primarily on fish of a certain age, and the effect of incremental mortality to the population may depend on whether that mortality occurs before or after the age at which compensatory mechanisms act. For example, if density dependence acts via competition among juvenile fish for resources (e.g., food or shelter) then removal of earlier life stages may have no effect on the population until the number of surviving larvae are reduced to the point that the available resource is not fully utilized. The number of fish surviving the juvenile stage, and thus also the adult population, would be stable. With such a compensatory mechanism, mortality of adult fish (e.g., by harvesting) would lead directly to a reduction in the adult population.

Compensatory effects are fundamental to the long-term persistence of fish populations (Kimmerer et al. 2000), but are only accounted for in specific types of fish population models. The forward projection models used in the EIS do not account for compensatory effects. The existence of compensatory effects can be evaluated using data on population size and recruitment. Both the analysis of compensatory effects and its application in stock assessment models require consideration of the entire fish population. Because the forward-projection model used in the OLV facility EISs considers only the fraction of the fish population that is entrained by the facilities, it does not (and cannot) address compensatory effects. The consequence of not including density-dependent compensation in the models is an overestimation of potential impacts on fish populations (Barnthouse 2002). This compounds the conservative bias associated with other assumptions used in the models. Expressing the potential impacts of OLV entrainment losses as an effective reduction in egg production allows these effects to be incorporated into stock assessment models that include the whole population, and that can include compensation effects.

3.2.4.3 Use of Fish Production as a Model Endpoint and Comparison to Fishery Landings

The endpoint of the forward projection model used in the EISs is foregone production, specifically, the weight of fish of harvestable age that is not produced as a result of entrainment of eggs and larvae. For harvestable species such as red drum, this endpoint is then compared to fishery landings, including commercial and recreational landings of different states and the GOM fishery as a whole. Comparison to fishery landings is inappropriate because:

- The benchmark is arbitrary
- Entrainment losses are not equivalent to fishery reductions.

The benchmark is arbitrary because a variety of different landing figures can be chosen for comparison, but none of them have a definite relationship to the sizes of the affected fish populations. For example, landings can be effectively changed by regulation (e.g., fisheries management decisions) and this will affect the comparison of OLV impacts to those landings, even if there has been no change in OLV entrainment or fish population levels.

Although the EISs do not directly equate entrainment losses to fishery reductions, the comparison alone carries that implication, and this can lead to misinterpretation of the overall effect of entrainment losses. Entrainment losses and fishery landings are only indirectly linked through the total fish population size. The functional relationship between entrainment losses and population size is different from the relationship between population size and fishery landings, and both can vary independently of the other. There is thus no technical basis for evaluating entrainment losses based on fishery landings, and furthermore, it is a rhetorically misleading approach. Evaluation of entrainment losses in terms of changes in overall population size is a more appropriate approach.

In addition, interpretation of projection of potential impacts to future fishery yields is further compounded by the uncertainty of future conditions. That is, in addition to uncertainties related to the model parameters, there is also uncertainty about other future potential impacts on fish stocks. These other effects may include changes in fishing pressure, weather effects such as storm damage to critical habitat or El Nino effects, spills, and introduction of new invasive species. Use of forward-projection models therefore implicitly requires some assumptions about the net present value of the fishery production, but do not explicitly incorporate either a discount rate or an estimate of changes in other factors that may affect fish stocks.

3.2.4.4 Correction for Entrainment Losses during a Life Stage

The effect of mortality is customarily represented by the survival fraction, as described previously. This allows the effect of mortality during a life stage to be easily calculated for other life stages. This approach to predicting survival is straightforward to apply to all life stages following the stage in which entrainment mortality occurs. In the example at the beginning of Section 3.2.4, the eggs were all subject to entrainment mortality prior to the larval stage for which the calculation was done. In such a case, the survival fraction can be simply calculated from the natural mortality rate, as in the example. Within the egg stage itself, however, entrainment mortality occurs continuously throughout the stage, rather than having occurred prior to the stage (this is true for larval stages as well). Consequently, the survival fraction cannot simply be calculated from the natural mortality rate. Instead, the survival fraction for the egg stage must take into account the entrainment mortality rate as well as the natural mortality rate. An adjusted survival fraction must therefore be used when entrainment mortality occurs during a life stage.

The exact value of the adjusted survival fraction can only be calculated if the entrainment mortality rate is known. Although the total numbers of eggs and larvae entrained can be estimated from SEAMAP data and water withdrawal rates, these total entrainment values can't be directly converted into entrainment mortality rates. Entrainment mortality rates can be estimated, however, by relating the rate of water usage at each facility to the volume of water affected (i.e., potentially subject to withdrawal) by the facility. Although such volume estimates could be readily developed for confined water bodies such as lakes, they are not easily definable for large open systems such as the GOM. Thus, the volume of water affected by each facility is not well established. No estimates of seawater volumes affected were made in the facility EISs. The EISs therefore do not calculate the exact value for the adjusted survival fraction. Instead, they use a formula for the adjusted survival fraction that is based on the assumption that all entrainment mortality occurs at the moment when half of the natural mortality has occurred. This is an arbitrary and inappropriate assumption, with no scientific justification given. As a result of this assumption, the adjusted survival fractions used in the EISs are inaccurate and their use reduces the accuracy of the predictive assessments.

The correct formula for the adjusted survival fraction is shown in Equation 1. The derivation of this formula is explained in Appendix A. The formula used in the EISs is reproduced here as Equation 2 (e2M 2005). The results of applying these two different formulae, using relevant life stage parameters and several different assumed entrainment mortality rates, are shown in Table 3-3.

$$S^* = \frac{e^{-kt_s}\left(\frac{e^{-mt_s}}{m}+t_s-\frac{1}{m}\right)}{e^{-(k+m)t_s}\left(\frac{1}{k+m}-\frac{e^{mt_s}}{k}\right)-\left(\frac{1}{k+m}-\frac{1}{k}\right)} \qquad \text{Eq. 1}$$

where:

S^* = adjusted survival fraction
k = natural mortality rate (/day)
m = entrainment mortality rate (/day)
t_s = stage duration (days)

$$S^* = 2e^{-kt_s}e^{-\ln\left(1+e^{-kt_s}\right)} \qquad \text{Eq. 2}$$

Table 3-3. Comparison of formulae for adjusted survival fraction

Stage	Natural mortality rate (k) (/day)	Stage length (t_s) (days)	Entrainment mortality rate (m) (/day)	True adjusted survival rate (S*)	EIS estimate of S*	EIS S* ----------- True S*
Red drum eggs	0.5	1	0.0001	0.840	0.755	90%
Red drum eggs	0.5	1	0.1	0.839	0.755	90%
Red drum larvae	0.3	22	0.0001	0.030	0.0027	9%
Red drum larvae	0.3	22	0.01	0.029	0.0027	9%
Red drum larvae	0.3	22	0.1	0.022	0.0027	13%
Red snapper larvae	0.3	27	0.0001	0.010	0.0006	6%
Red snapper larvae	0.3	27	0.01	0.009	0.0006	6%
Red snapper larvae	0.3	27	0.1	0.006	0.0006	9%

In Table 3-3, the true adjusted survival rate (S*) is calculated using Equation 1, and the EIS estimate of S* is calculated using Equation 2. The several examples shown, using life stage parameters for GOM species evaluated in the EISs, demonstrate that the EIS estimates of the adjusted survival fractions range from about 10 percent to 90 percent of the true values. The consequence is that survival of entrained eggs and larvae, had they not been entrained, would be greater than is estimated in the EISs, but by widely varying amounts.

An important aspect of the correct calculation of the adjusted survival fraction is that it is insensitive to the entrainment mortality rate when the entrainment mortality rate is small relative to the natural mortality rate. For example, the adjusted survival fraction for red drum eggs is effectively the same at all entrainment mortality rates less than about 20 percent of the natural mortality rate. For red drum larvae, the critical value is about 3 percent rather than 20 percent. So although, as noted previously, the entrainment mortality rate is not well known, it does not need to be well known if it is at least known to be small relative to the natural mortality rate. A simple estimate of the likely magnitude of the entrainment survival rate can be made using the same spatial extent that was used in the EISs to estimate egg and larval abundances. For example, the area around Gulf Landing that was used to select SEAMAP data for egg abundances is about 5,432 km^2 (e2M [2005] contains two different values for this area, but both are wrong). The water depth averages about 15 meters. This area and depth is equivalent to 2.1×10^{7} million gallons of water. The Gulf Landing ORV system takes in 136 million gallons of water per day, and this corresponds to a proportional seawater withdrawal rate of approximately 6.5×10^{-6} /day. Assuming that ichthyoplankton are uniformly distributed throughout the volume of seawater (an assumption inherent in the abundance calculation), and assuming that all entrained ichthyoplankton are killed, the entrainment mortality rate will be equivalent to the seawater usage rate—that is, 6.5×10^{-6} /day. This entrainment mortality rate is many orders of magnitude less than the natural mortality rates for fish eggs and larvae and is also much smaller than the uncertainty in natural mortality rates (Gallaway 2005). This comparison alone indicates that the impacts of OLV usage on fish populations will be minor relative to natural mortality. Different estimates could be made of the volume of water affected by the Gulf Landing facility, and they would result in different estimates for the entrainment mortality rate. However, the affected area would have to be quite small for the entrainment mortality rate to be as high as a few percent of the natural mortality rate. In contrast, the affected area could reasonably be considered to be quite a bit larger than the area used in this example calculation. In particular, the affected area could be considered to be the entire area of the GOM within which a species is found. Therefore, because entrainment mortality rates are clearly far less than natural mortality rates, the exact formula for the adjusted survival fraction should be used.

3.2.4.5 Use of an Egg-Equivalent or Fecundity Endpoint

The effect of all of the compounded uncertainty described in previous sections on model predictions is substantial, although not explicitly quantified, in the EISs prepared for OLV facilities. Because of this compounded uncertainty, the predictions resulting from this approach are likely to be inaccurate. However, the uncertainty could be minimized by using a different model endpoint. From the standpoint of evaluating effects on the fish population, changes in annual egg production are as relevant, if not more relevant, than changes in equivalent yield and comparisons to fishery landings. Projecting from observed egg and larval abundance to the initial number of eggs spawned also requires life history parameters for instantaneous mortality and stage duration, but it requires only parameters for the egg and larval stages, not those for juveniles and adults, and also does not require parameters for growth rates and length:age relationships. Thus, this approach is much less uncertain and more scientifically defensible than the forward-projection methods used in the EISs. Gazey (2005) also recommends that potential impacts from entrainment be expressed in terms of total equivalent eggs rather than in terms of fishery production. Stock assessments for individual species (e.g., Porch 2000; Schirripa and Legault 1999) contain estimates of annual egg production that can serve as a basis for interpreting the magnitude of potential entrainment impacts on population fecundity. It is our recommendation that that potential entrainment impacts be expressed in terms of total equivalent eggs rather than in terms of fishery production.

For example, Porch (2000) summarizes red drum fecundity, annual red drum egg production in the GOM, and recreational landings. From these data, the annual egg production of red drum in the GOM is approximately 5 trillion to 10 trillion eggs (estimated for 2005 from Figures 23 and 26 of Porch [2000]). Each female fish produces millions of eggs per year: 5.7 million eggs per year for a 5-year old fish, 16 million eggs per year for a 10-year old fish, and 32.5 million eggs per year for a 30-year old fish. Recreational harvest of red drum was 2.6 million fish in 1997, the latest year for which statistics are reported. These figures provide a basis for comparative evaluation of potential OLV impacts, when those impacts are expressed on a fecundity basis. If half of the fish caught recreationally are females, and their average fecundity is equivalent to that of a 5-year old fish, the 1997 recreational harvest would eliminate the production of approximately 7.4 trillion eggs per year. Equivalent egg losses as a result of entrainment of eggs and larvae in OLV facilities can be compared to this value for a valid and scientifically defensible assessment of the potential for adverse impacts of LNG facilities.

Using the fecundity hindcasting model described in EPRI (2004), red drum population data from Porch (2000), egg and larval life history data recommended by Gallaway (2005), and appropriate evaluations of ambiguous taxonomy and seasonality, egg equivalents and equivalent fecundity effects have been calculated for red drum in the vicinity of Gulf Landing. The egg equivalents of entrained red drum eggs and larvae are approximately 600 million eggs (Table 3-4). This calculation uses the correct method for calculating adjusted survival fractions, as described in Section 3.2.4.4. The result is not adjusted to account for the effects of all of the other sources of bias and uncertainty described in previous sections. Consequently this is not the most accurate estimate that could be made, but it was obtained by a method comparable to that used in the Gulf Landing EIS (e2M 2005), except for the correction of clearly inappropriate and erroneous quantitative aspects of the method—and the use of an egg equivalent endpoint.

Use of the egg equivalent endpoint indicates that red drum entrainment at Gulf Landing will be on the order of 0.006 to 0.01 percent of annual egg production in the GOM. Using data from Porch (2000) to calculate the lifetime fecundity of a female red drum, the egg equivalent endpoint can also be expressed in terms of the number of spawning females removed from the population. The expected lifetime fecundity of female red drum is a little over 73 million eggs, so the egg equivalent endpoint corresponds to a loss of 8 female fish. Assuming a 1:1 sex ratio (i.e., a total of 16 fish lost), this is equivalent to 0.0006 percent of the annual recreational harvest of red drum reported by Porch (2000).

The egg equivalent model was also applied to red snapper at the Gulf Landing facility, using data from Schirripa and Legault (1999), Gallaway (2005), and e2M (2005). The egg equivalents of entrained red snapper eggs and larvae are 2.18 million eggs. This corresponds to a loss of 0.009 adult female fish.

Even the projection from larval abundance back to initial egg abundance relies on life history parameters; specifically, the stage durations and instantaneous mortality rates for eggs and larvae. Because of the non-linearity of the mortality function, predictions of mortality or initial egg abundance are more sensitive to uncertainty in the life history parameters than to other aspects of the estimation and modeling process. Consensus on the most appropriate life history parameters to use for each species of importance could be obtained by convening a panel of

Table 3-4. Egg equivalents for red drum at Gulf Landing

Life Stage	Entrainment Mortality[a] (number)	Instantaneous Mortality Rate (/d)	Stage Duration (d)	Survival Fraction	Adjusted Survival Fraction[b]	Equivalent Number of Eggs Spawned
Egg	7,072,000	0.5	1	0.607	0.787	9,790,028
Larva	16,000,000	0.3	22	0.001360368	0.151	582,975,568
					Total number of equivalent eggs[c]:	592,765,597

Note: EPRI - Electric Power Research Institute

[a] Larval entrainment is calculated as described in section 3.2.1.3 of the text. Egg entrainment is estimated to be 44.2 percent of this, as in e2M (2005).

[b] The adjusted survival fraction is calculated by the correct method, as described in the text, instead of by the EPRI method used in the environmental impact statements.

[c] Annual egg production of red drum in the Gulf of Mexico is 5–10 trillion eggs (Porch 2000).

highly qualified fisheries scientists to review all of the available information and to recommend likely values and upper and lower bounds on those values.

3.2.5 Summary of Uncertainty and Bias in Mortality Assessments

The factors discussed in previous sections of this report have varying effects on the assessment of entrainment mortality. These factors can be generally categorized as affecting the precision and accuracy, or uncertainty and bias, of the mortality estimates. Some factors have one type of effect, and some have another type of effect. Summarizing all of the various types of effects in quantitative terms allows their combined influence to be evaluated.

A quantitative estimate of the magnitude of each type of effect has been made for red drum entrainment at the Gulf Landing facility. Bias in the mean (estimated) mortality value, uncertainty in the mean, and bias in the range of uncertainty have all been estimated separately, as appropriate for each factor. These values are shown in Table 3-5. The negative and positive factors shown in the first two categories shown in Table 3-5 are expressed relative to an accurate estimate of mortality, and the third is expressed relative to the Gulf Landing EIS results. A positive factor indicates that an overestimation occurs in the EIS prediction relative to the true value, and a negative factor indicates that an underestimation occurs. Figure 3-10 also shows a graphical depiction of the bias associated with various factors. Each of the estimates in Table 3-5 is explained in the following sections.

3.2.5.1 Use of Forward Projection Models

The use of forward projection models excludes consideration of compensation effects, which introduces bias, and involves the use of relatively poorly known life history parameters, which introduces uncertainty. The amount of bias cannot be accurately estimated without actually applying stock assessment models with and without entrainment effects. Thus, there is considerable uncertainty in the amount of bias, as shown in Table 3-5 and Figure 3-10. If compensation were complete, then the amount of bias would be very large.

The limits shown for uncertainty in the mean value represent the range of estimates produced by the maximum and minimum survival rate values for larvae (Gallaway 2005) relative to the base case. Projection through additional life stages will impose further factors on top of these, so the actual uncertainty will be larger. A probabilistic analysis would need to be done to address the combined effect of all of these. The values shown are likely representative (if not minimum) values for the range of uncertainty. Failure to consider the complete range of variability in the EIS results in a negative bias to the estimated range of uncertainty.

3.2.5.2 Vertical Distribution of Ichthyoplankton Relative to Seawater Intakes

As described in Section 3.1.1, the vertical migratory behavior of red drum larvae is likely to remove them from the vicinity of the seawater intake for at least half the day. Failure to

Table 3-5. Estimates of bias and uncertainty for red drum and the Gulf Landing facility

Item	Bias in Mean Value[a]		Uncertainty in Mean Value[b]		Bias in Range of Uncertainty[c]	
	Negative	Positive	Negative	Positive	Negative	Positive
Use of forward projection models through multiple life stages with poorly known parameters		1.5–10	0.02	5.6	5	
Vertical distribution of ichthyoplankton relative to seawater intakes		2				
Location of facilities relative to spawning and hypoxic zones		2				
Net efficiency	2					
Failure to correct for ambiguous taxonomy on a sample-specific basis		2				
Assumption of 100 percent entrainment mortality		1.6				
Error in survival fraction calculation	2					
Variable spatial coverage of SEAMAP data in the region of the facilities			0.5	1.2	0.3	
Failure to properly account for systematic seasonal variability						4
Incomplete temporal coverage of SEAMAP data						

Note: EIS - environmental impact statement
SEAMAP - Southeast Area Monitoring and Assessment Program

The effects for other species may be different in some respects than those shown here for red drum, but overall, red drum is believed to be a reasonably representative species as well as a commercially important one.

[a] The values for bias in the mean value represent the bias of the EIS prediction relative to the likely true value.

[b] The values for uncertainty in the mean value represent the range of variation that the true value (e.g., mortality) may have relative to the value used in the EISs. For example, because of variable spatial coverage of SEAMAP data in the vicinity of Gulf Landing, the true abundance (and thus entrainment and mortality) of red drum may be from 50 to 120 percent of the value predicted by the EIS.

[c] The values for bias in the range of uncertainty represent the amount by which uncertainty (e.g., width of the confidence interval) is underestimated or overestimated in the EISs relative to the true value.

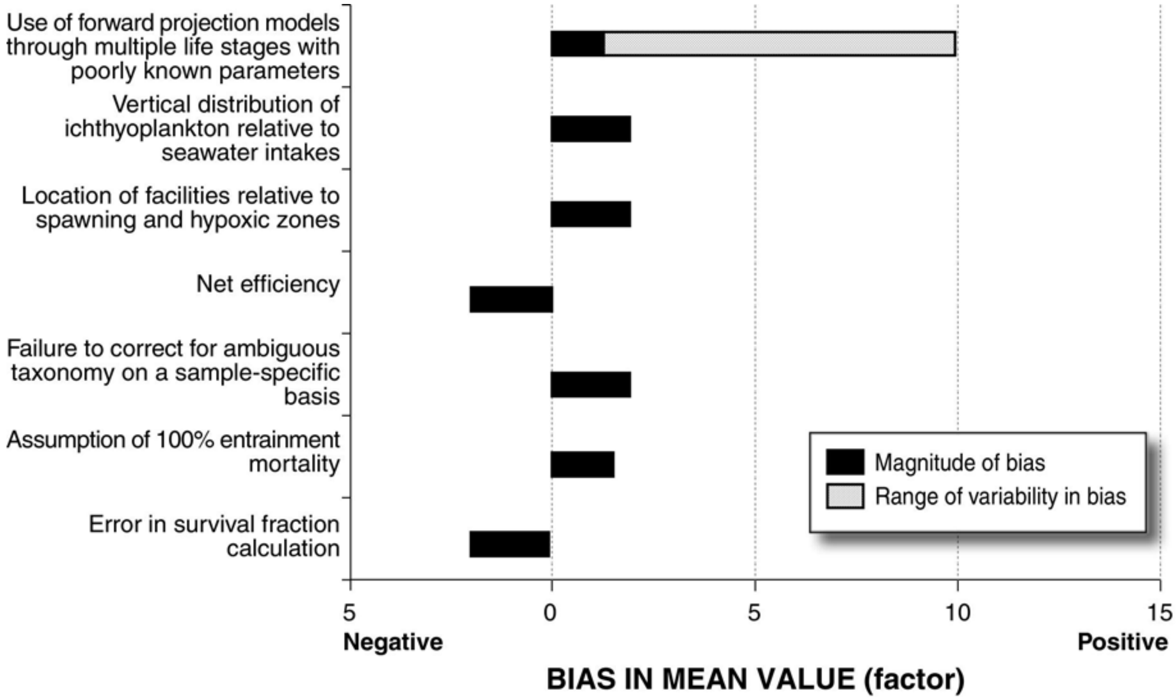

Figure 3-10.
Estimates of bias and uncertainty for red drum and the Gulf Landing facility

consider this effect is likely to result in an overestimate, by a factor of 2, of entrainment and mortality.

3.2.5.3 Location of Facilities Relative to Spawning and Hypoxic Areas

The Gulf Landing facility is located away from the spawning and larval settlement areas used by red drum. Consequently, eggs and larvae found in the location of Gulf Landing may never mature as a result of these physical effects. Although there are no data to quantitatively assess the magnitude of these effects, incremental mortality of 50 percent seems likely. Failure to consider this effect is equivalent to a positive bias of 2.

3.2.5.4 Net Efficiency

Although a net efficiency factor of 3 was applied to both eggs and larvae in the EISs, a higher factor is probably appropriate for eggs, which make up about 30 percent of all ichthyoplankton. The value given is based on professional judgment rather than calculation.

3.2.5.5 Correcting for Ambiguous Taxonomy on a Sample-specific Basis

The result of correcting ambiguous taxonomy on a sample-specific basis for red drum at Gulf Landing is to reduce the estimated abundance by approximately a factor of two. Therefore, failing to make the correction appropriately can be expected to lead to an estimate that is biased high by a factor of 2.

3.2.5.6 Assumption of 100 Percent Entrainment Mortality

Conservatively assuming that larval avoidance occurs at only half the rate measured by Zeitoun et al. (1981), and given that larvae make up 70 percent of the ichthyoplankton, the result would be that actual entrainment would be about 63 percent. Conversely, failure to account for this factor will introduce a positive bias of about 160 percent. If some eggs or larvae survive passage through the OLV system, this bias factor would be larger, but this effect has not been quantitatively estimated.

3.2.5.7 Error in the Survival Fraction Calculation

As described in Section 3.2.4.4, the Gulf Landing EIS overestimates the natural mortality of entrained eggs and larvae. Consequently, more of the entrained eggs and larvae would have survived than the EIS estimates. Hence, this aspect of the calculations performed in the EISs has a negative bias. Calculations using the entrainment estimates and life history parameters that were used in the Gulf Landing EIS (although these are inaccurate for other reasons) indicate that the bias for red drum is approximately a factor of two. Thus, Figure 3-10 shows that the error in the survival fraction calculation results in a negative bias of a factor of 2.

3.2.5.8 Spatial Variability of SEAMAP Data

As shown in Figure 3-5, most of the SEAMAP stations near Gulf Landing are either several miles inshore or several miles offshore of the facility. Red drum larvae are 2.2 times more abundant at the stations that are closer to shore than at those farther from shore. Actual abundances at the facility could be either of these two values instead of the mean, and the uncertainty in the mean is therefore equivalent to this range of variation. Failure to account for this uncertainty also imposes a low bias on the overall uncertainty estimate.

3.2.5.9 Systematic Seasonal Variability

Failure to account for systematic seasonal variability leads to overestimation of the overall uncertainty estimate, as described in Sections 3.2.1.2 and 3.2.1.3. The uncertainty bias estimate in Table 3-5 is the relative difference between the upper 95 percent confidence limit and the mean for the EIS estimate (e2M 2005) and the corrected estimate (Section 3.2.1.3).

3.2.5.10 Incomplete Temporal Coverage of SEAMAP Data

Table 3-5 does not contain any values for this factor because red drum spawn, and the larvae mature, entirely within the annual period of frequent SEAMAP observations. For other species, however, the incomplete temporal coverage of SEAMAP data could increase the range of uncertainty for the mean mortality value.

3.2.5.11 Synthesis

Although some of the estimates of bias and uncertainty are themselves uncertain, the summary information in Table 3-5 and Figure 3-10 allows some general conclusions to be drawn about the accuracy and precision of mortality estimates for red drum at Gulf Landing. In particular:

- The net effect of the various sources of bias is positive: that is, the EIS (e2M 2005) has substantially overestimated red drum mortality.
- Some factors that tend to substantially bias high the uncertainty estimates in the EIS relative to an accurate estimate of uncertainty, and some factors tend to substantially bias it low. The balance between these is unknown, and as a result, the uncertainty of the EIS estimates is also effectively unknown.

The potential extent of overestimation of red drum mortality can also be evaluated by contrasting the EIS results with the results of a model that includes:

- A corrected abundance calculation (Section 3.2.1.3)
- More accurate estimates of life history parameters (Gallaway 2005)
- A correction to the survival fraction calculation (Section 3.2.4.4).

The EIS predicts annual red drum mortality equivalent to approximately 28,000 age-1 equivalent fish (e2M 2005, Table G-14). In contrast, the corrected model predicts mortality of 5,600 age-1 equivalent fish or 8 spawning females. The difference between these two estimates is a result of the inclusion of uncertain life history parameters for juvenile fish in the age-1 equivalent estimate. The age-1 equivalent estimate is therefore more uncertain than the fecundity estimate. This uncertainty evidently takes the form of a positive bias (overestimate) in the estimated impact. The EIS estimate of impact is 1,750 times higher than the more accurate fecundity-based estimate. The known biases account for part of this overprediction. Some of the other sources of uncertainty described previously may impose additional bias that accounts for the remainder of the overprediction.

3.2.6 Ecosystem Effects

Several sets of comments on the EISs note that they do not address ecosystem-level effects. Ecosystem-level effects are the effects on other members of the aquatic community that result from entrainment losses, including losses of phytoplankton and zooplankton as well as ichthyoplankton. The types of potential effects are varied, and depend on the ecological role of the ichthyoplankton that are killed, as well as on other characteristics of the ecosystem. The effects may include:

- Reduction in food resources (phytoplankton or prey populations)
- Reduction in predator populations
- Localized increase in dissolved oxygen in the lower seawater column
- Increase in detrital organic matter.

Reduction in prey populations may be important for species that are prey-limited. Reduction in predator populations may be important for species that are predator-limited. An increase in detrital organic matter may be important for food-limited detritivores, and may also affect the rate of nutrient cycling throughout the system, with effects on the entire ecosystem that could range from increased hypoxia to increased primary production. Other effects, such as alteration of competitive relationships among species, may also occur.

To completely account for all of the possible types of ecosystem effects would require a comprehensive ecosystem model for the GOM. Such a model would have to represent not just the population dynamics of all entrained species, but would have to integrate this with a representation of the food web that tracks nutrient or energy flow throughout the system. Creation and validation of such an energetics-based ecosystem model for the GOM would be extremely challenging, if not impossible, because the Gulf is not an energetically closed system. Because potential impacts on ichthyoplankton populations appear to be minor, the precision of an ecosystem model would have to be very high for the model to provide a reliable analysis of the potential impacts of OLV on ichthyoplankton. Inherent uncertainty in much of the data and many of the relationships that would have to be incorporated into such a model is substantially greater than the anticipated minor level of effects, with the consequence that achieving such a level of model precision is very unlikely to be feasible.

Without an ecosystem model to completely account for all possible types of ecosystem effects, the question of potential ecosystem impacts can probably be best addressed through an analysis of the potential impacts of OLV facilities relative to other typical events and processes that affect the ecosystem. Relevant events and processes include those that are both natural and anthropogenic. These may include:

- Annual variability in survival resulting from natural variation (e.g., temperature variation)
- Annual variability in organic loading from the Mississippi River and from primary productivity
- Fractions of fish stocks harvested annually, including harvests of prey and predators of the species entrained by OLV facilities

- Bycatch and seafloor impacts from commercial fishing and trawling
- Entrainment losses due to use of cooling water by cargo, other shipping, and industrial operations.

Contrasting the changes in fish stocks and detrital carbon resulting from OLV entrainment to these other quantities may provide an indication of the relative magnitude of potential OLV impacts. The uncertainty of available data must be carefully assessed and tracked during this analysis. The results of this analysis can be either that the effects of OLV entrainment are negligible, or that the effects of OLV entrainment are potentially non-negligible. This approach does not provide a quantitative (e.g., statistical) means of distinguishing negligible from potentially non-negligible effects, although criteria such as the range of natural variation and the uncertainty bounds on other processes are reasonable benchmarks for drawing a distinction. This approach also does not provide a means to estimate the magnitude, or even the nature, of ecosystem-level effects if they are judged to be non-negligible. Thus, it will not provide a definitive answer to the question of how large any ecosystem-level effects may be, but it does provide a feasible and rapid means of determining whether such effects are likely to be negligible.

3.3 Cumulative Impacts to Fisheries Resources

The Council on Environmental Quality's regulations for implementing NEPA define cumulative effects as "impacts on the environment which result from the incremental impact of the action when added to other past, present, and reasonably foreseeable future actions" (40 CFR§1508.7). Cumulative impact assessments are done as part of an EIS to account for the combination of effects from multiple actions over time.

One of the criticisms of the impact assessments conducted to date is that cumulative impacts, or impacts to fisheries from multiple LNG facilities in the GOM, have not been adequately assessed. To assess the scientific validity of the approaches used to assess potential cumulative impacts from multiple OLV facilities in the northern GOM, we evaluated the cumulative impact assessments for the EISs conducted to date, as well as the cumulative impact assessment conducted by NMFS and provided in their comments on the Compass Port and Gulf Landing EISs (NMFS 2005a,b). The questions to which we sought answers were:

- What is the best method to account for potential cumulative impacts of multiple facilities that would simultaneously be causing entrainment mortalities in the GOM?
- Can geographic limits of individual stocks be identified for key species, and how does this influence the method used for grouping facilities for cumulative impact analysis?
- Have the cumulative impact assessments been rigorously conducted? And, are the methods used scientifically valid given the uncertainties associated with the entrainment mortality estimates?

3.3.1 Methods Used

Cumulative impacts to fishery resources potentially resulting from the development of multiple LNG facilities using OLV technology in the GOM have been assessed in the EISs using several metrics and approaches. Four of the seven assessments (Main Pass Energy Hub, Gulf Landing, Compass Port, and Pearl Crossing) used an additive quantitative approach to assess potential cumulative impacts, while three of the facilities (Gulf Gateway, Beacon Port[7], and Port Pelican) assessed potential cumulative impacts only on a qualitative basis. For those facilities that used quantitative approaches, additive equivalent yield metrics were used to estimate potential cumulative impacts. Table 3-6 summarizes the various approaches used in the EISs to assess cumulative impacts from multiple LNG facilities in the GOM. The following methods, or some combination thereof, were used to assess potential cumulative impacts for Main Pass Energy Hub, Gulf Landing, Compass Port, and Pearl Crossing. One method was to compare projected losses in fish stocks on an adult equivalent yield basis to recreational harvest in pounds of fish (USCG and MARAD 2004a). Another method was to compare potential impacts to the stock with total landings, both commercial and recreational, in pounds of fish (USCG and MARAD 2004a, 2005a,b,c). Some fish species (i.e., anchovy) were assessed on a biomass lost basis (USCG and MARAD 2004a, 2005b). Some of these comparisons were done for the entire GOM, some for an individual state, some for both. As stated earlier in this report, comparisons of projected adult equivalent yield to fishery landings are inappropriate because landings are not indicative of fish population size and because the fishery landing statistics used are arbitrary (e.g., for an individual state or for the entire GOM).

Some of the cumulative impact assessments in the EISs account for potential impacts to fisheries from all existing and proposed OLV facilities in the Gulf (USCG and MARAD 2005c), while others group facilities by geographic location[8] (USCG and MARAD 2005b). Some assessments considered only those facilities with complete license applications and NEPA documentation (USCG and MARAD 2004a, 2005a.) The Main Pass Energy Hub EIS (USCG and MARAD 2005c) evaluated potential cumulative impacts from all seven facilities that use or propose to use OLV technology. The assessments for the other facilities used some grouping (e.g., geographic, ecological, or regulatory) of facilities in estimating potential cumulative impacts.

The EISs for the Main Pass Energy Hub, Gulf Landing, and Compass Port facilities also compared the LNG facilities' seawater intakes to cargo ship engine cooling water usage in the context of assessing cumulative impacts. For example, in the Main Pass Energy Hub EIS, USCG and MARAD (2005c) compare the 386.6 billion gallons per year for the seven proposed ports' warming water to 3.6 trillion gallons per year used for cargo ship engine cooling water, and conclude the proposed ports' warming water is equal to only 11 percent of cargo ship cooling water. Similarly, for the Gulf Landing and Compass Port EISs, USCG and MARAD (2004a, 2005a) compared the 49.7 billion gallons warming water per year for LNG facilities with complete Deepwater Port applications and approved public draft NEPA documentation

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[7] Note that the cumulative impacts assessment for Beacon Port was conducted as part of the Environmental Report for this facility, and no EIS has been conducted to date.

[8] Some EISs used a combined approach evaluating cumulative impacts Gulf-wide as well as on an individual state basis.

Table 3-6. Cumulative impact assessments for Northern Gulf of Mexico LNG facilities

Facility	Facilities Included in Analysis	Assessment Endpoint	Approach	Reported Results	Conclusions		Page(s)
Main Pass Energy Hub	Beacon Port, Compass Port, Gulf Gateway Energy Bridge, Gulf Landing, Main Pass Energy Hub, Pearl Crossing, and Port Pelican	Annual equivalent yield of menhaden, red drum, and red snapper compared to 2003 total GOM landings.	Equivalent yield compared to landings for the entire northern GOM (all facilities added together), for total NE GOM (Main Pass and Compass Port), and total NW GOM (all others). Equivalent yields for Gulf Gateway, Beacon Port, and Port Pelican were extrapolated from Gulf Landing data.	Cumulative impacts of all facilities would represent <1% of the total GOM landings for menhaden and red snapper, and 2.63% of total GOM landings for red drum. Cumulative impacts from the NE GOM facilities (Main Pass and Compass Port) would be <1% of 2003 NE GOM landings for Gulf menhaden and red snapper, and 1.32% for red drum. ”… the greatest effect that the Proposed Action would have on any given species would be on red drum. The cumulative effect of seven deepwater ports in the entire GOM, in a year would be equivalent to an additional 0.88 percent fishing stress on a population. The cumulative effect of two deepwater ports in the entire GOM, in a year would be equivalent to an additional 0.9 percent fishing stress on a population.”	Long-term minor adverse impacts on fisheries, negligible compared to the cumulative impacts of shipping and fishing.	2005 DEIS Section 6 Cumulative and Other Impacts	pp. 6-21 to 6-25
Gulf Landing	Gulf Landing, Port Pelican, Gulf Gateway Energy Bridge (facilities with complete Deepwater Port applications and approved public draft NEPA document)	Annual equivalent yield of red drum compared to 2002 GOM and Louisiana landings	Summed annual yield estimates for all facilities. Assumed that Port Pelican would have a similar impact as Gulf Landing.	Equivalent yield of red drum potentially lost would be approximately 1 to 3% of the total landings (commercial plus recreational) in the GOM, and 1.4 and 4.3% of the total landings (recreational only) in Louisiana for red drum in 2002. “The cumulative impact on red drum for the Gulf Landing and Port Pelican ports could represent from 2 to 6 percent of the total combined commercial and recreational landings the GOM and nearly 3 to 9 percent of the recreational landings in Louisiana in 2002. The cumulative impacts from the two ports would be less than 1 percent of the magnitude of the last recorded commercial landings.”	Long-term minor adverse impact on fisheries.	2004 Final EIS Section 5 Cumulative and Other Impacts	pp. 5-6 to 5-9
		Annual equivalent yield of Gulf menhaden and red snapper compared to 2002 GOM and Louisiana landings	Summed annual yield estimates for all facilities. Assumed that Port Pelican would have a similar impact as Gulf Landing.	“The cumulative equivalent yield estimates for Gulf menhaden would be below 1 percent of the commercial landings in the GOM and Louisiana in 2002. The cumulative equivalent yield estimates for red snapper would also range below 1 percent of the commercial and recreational landings in the GOM from 0.5 to 1.1 percent of the Louisiana commercial and recreational landings in 2002.”			
		Bay anchovy biomass	Assessed bay anchovy as a forage fish and as an indicator for indirect impacts on essential fish habitat (EFH). Used biomass losses compared to total GOM biomass estimates for bay anchovy and other forage fish.	Predicted biomass losses for bay anchovy associated with the proposed Gulf Landing facility were <1% of the total GOM biomass estimates for taxa associated with bay anchovy and other forage fish.			
Compass Port	Compass Port, Gulf Landing, Port Pelican (facilities with complete Deepwater Port applications and approved public draft NEPA document; did not include Gulf Gateway Energy Bridge because of different deep-water habitat)	Annual equivalent yield of red drum, Gulf menhaden, and red snapper compared to 2002 GOM landings	Summed annual yield estimates for all facilities.	Predicted annual equivalent yield of red drum that might be taken by the three facilities would represent up to 3% 2002 landing levels.	“With the exception of red drum, the cumulative effects from the intakes of the three proposed LNG facilities appear to constitute minor adverse impacts on the key species. For red drum, we have estimated that the Proposed Compass Port Deepwater Port would represent less than 1.44 percent of the 2002 landings of this species, a minor, long-term adverse impact.”	2005 DEIS Section 6 Cumulative Impact of Proposed and Alternative Actions and Other Impacts	pp. 6-9 to 6-12

Table 3-6. (cont.)

Facility	Facilities Included in Analysis	Assessment Endpoint	Approach	Reported Results	Conclusions		Page(s)
		Bay anchovy biomass	Assessed bay anchovy as a forage fish and as an indicator for indirect impacts on EFH. Used biomass losses compared to total GOM biomass estimates for bay anchovy and other forage fish.	Predicted biomass losses for bay anchovy were <1% of the total GOM biomass estimates for taxa associated with bay anchovy and other forage fish.			
Pearl Crossing	Pearl Crossing, Gulf Landing, Port Pelican, and Beacon Port projects. Did not include Gulf Gateway, Compass Port, and Main Pass Energy Hub due to location in an ecologically different environment and their distance from the northern GOM.	Total catch loss for red drum, red snapper, and menhaden compared to Louisiana landings.	Summed catch loss estimates for all facilities.	"Based on the total catch loss of red snapper and menhaden, and biomass loss of anchovies, if all of the projects were built and operated the impact on these populations (and likely similar species) would be much less than 1 percent of Louisiana landings and would be considered a minor impact on the fisheries resources of this region. The cumulative catch loss of all four projects together is estimated to be 3.1 percent of the annual red drum harvest (i.e., 3.1 percent of the total red drum currently harvested by fishermen in the area). The amount of loss if all four projects were operating would be considered a moderate impact on that species."	Minor impact on red snapper and menhaden. Moderate impact on red drum.	2004 DEIS Cumulative and Other Impacts	pp. 6-8 to 6-13
		Annual equivalent yield (biomass) for anchovy as a percent of Louisiana landings	Summed biomass loss estimates for all facilities.	Facilities would account for <1% of Louisiana landings.	Minor impact on anchovies.		
Gulf Gateway			Did not quantitate cumulative impacts.	"It is anticipated that the potential cumulative impacts associated with the two ports would be indistinguishable from most other anthropogenic impacts on fisheries resources and EFH, and would be inconsequential compared to natural mortality."		2003 Final EA Section 5 Cumulative and Other Impacts	p. 5-5
Beacon Port			Did not quantitate cumulative impacts.	"The Proposed Action should have an inconsequential impact to commercial fishing in the OCS. The incremental impact of the Proposed Action in consideration of other planned LNG DWPs is not expected to have an adverse impact to commercial fisheries of the northern GOM."		2004 Environmental Report, Topic Report 10, Cumulative Impacts	pp. 10-9 to 10-10
Port Pelican			Did not quantitate cumulative impacts.	"The incremental contribution of the Proposed Action's impacts on fisheries resources and EFH, as well as the impact of future natural gas deepwater ports in the GOM, would be indistinguishable from most other anthropogenic impacts to fisheries resources and EFH and would be inconsequential compared to natural mortality."		2003 Final EIS Section 5 Cumulative and Other Impacts	p. 5-4

(i.e., Gulf Landing, Port Pelican, and Gulf Gateway Energy Bridge) to the 3.6 trillion gallons per year used for cargo ship engine cooling water and concluded that the shipping industry uses approximately 72 times as much water.

The EISs that quantitatively evaluated potential cumulative impacts have used an additive approach where the predicted entrainment impacts from two or more facilities are evaluated as a proportion of the total GOM fishery or as a proportion of state or regional landings (Table 3-6). The assumption of additive effects is not necessarily appropriate, given the existence of compensatory effects on population growth. In accordance with the recommendation that individual facility impacts should be assessed on the basis of changes to egg abundance and evaluated using stock assessment models, cumulative impacts should also be evaluated using an egg equivalent basis.

3.3.2 Inherent Uncertainties

The uncertainties associated with the cumulative impacts assessments include those that are inherent in the entrainment mortality estimates (e.g., variability in the estimates of ichthyoplankton density and growth and mortality of ELSs). For example, natural mortality for the larvae of red drum has been shown to be highly variable, with order-of-magnitude differences in the available estimates (Scharf 2000). This variability in the natural mortality rate of red drum is likely the parameter driving the variability in the estimates of potential cumulative impacts, as illustrated by the range of impacts estimated by NMFS (2005a) in their comments on Gulf Landing (0.5 to 12.4 percent of GOM harvest). Using low, median, and upper bound estimates of the model input parameters, or conducting a probabilistic analysis are methods that might be used to compensate for and/or quantify such uncertainty.

Other uncertainties are associated with various methodologies used to assess potential cumulative impacts. For example, some of the cumulative impact assessments in the EISs account for potential impacts to fisheries from all eight existing and proposed OLV facilities in the Gulf, others group facilities by geographic location (e.g., northeast GOM), and some assessments only considered those facilities with complete license applications and NEPA documentation (this assumes the other proposed facilities might not get built). Considering only those facilities with complete license applications and NEPA documentation may underestimate potential cumulative impacts presuming all eight proposed LNG facilities using OLV technology eventually are developed in the GOM. This is unlikely, as one application (Pearl Crossing) has already been withdrawn. Alternatively, assessing cumulative impacts for all GOM facilities may overestimate cumulative impacts, depending on which facilities actually get built and the population characteristics for the key species evaluated. For example, if there are distinct populations of a given species delimited by geographic location (e.g., northeastern GOM), it would not be appropriate to assess Gulf-wide cumulative impacts for that species. This concept is explored further in the subsection on population characteristics of key species below.

There are also uncertainties associated with the units used to measure potential cumulative impacts. Comparisons of projected adult equivalent yield to fishery landings are inappropriate because landings are not indicative of fish population size and because the landing statistics used are arbitrary (e.g., recreational vs. commercial, and individual state vs. the entire GOM). Comparisons between facilities' cumulative impact assessments (and cumulative impact claims and assessments set forth by the NGOs and others) should be viewed with caution to ensure that the comparative assessments are using an "apples to apples" approach.

3.3.3 Population Characteristics for Key Species

The EISs and the assessment conducted by NMFS have applied different approaches in grouping the LNG facilities for the assessment of potential cumulative impacts. If the geographic limits of individual stocks can be identified for key species, this would be an argument in favor of geographic grouping of facilities for cumulative impact assessment. Using red drum as an example, according to Porch (2000), "the best genetic evidence suggests that the degree of intermixing between Gulf red drum populations depends on their proximity to one another." This idea of overlapping subpopulations of red drum depending on geographic location is further supported by the study by Gold and Turner (2002). This study indicates site fidelity for red drum in the northern GOM and suggests that there is some separation of subpopulations despite the fact that limited movement between adjacent bays and estuaries occurs at ELSs and juvenile stages of this species. Gold and Turner (2002) suggest that management planning for red drum should be carried out on a regional basis, not on a state-by-state basis or for the entire northern Gulf. This concept would apply for cumulative impact assessment as well.

This suggests that addressing potential cumulative impacts on the basis of an individual state fishery, or for the entire northern GOM would be inappropriate for species such as the red drum and may result in an overestimation of the cumulative impacts of multiple LNG facilities. This notion of regional intermixing of populations suggests that the cumulative impact assessments should consider grouping the OLV facilities geographically when assessing impacts to fish that exhibit site fidelity, such as the red drum.

On the other hand, other species such as red snapper are considered one population in the GOM. Therefore, management of this species as a single stock is appropriate (Schirripa and Legault 1999). For a species such as red snapper, all OLV facilities in the GOM would have to be included in the cumulative impact analysis to determine potential impacts to the entire stock. The most appropriate method for assessing potential cumulative impacts is therefore species-specific, and geographical grouping of facilities would not be applicable to species with one Gulf-wide unit stock. The population dynamics for other key species would need to be similarly researched to determine the best methods for cumulative impact assessment for these species.

3.3.4 Critique of Methods

One of the criticisms of the OLV impact assessments conducted to date is that potential cumulative impacts, or impacts to fisheries from multiple LNG facilities in the GOM, have not been adequately assessed. We reviewed the cumulative impact assessments for the proposed or existing OLV facilities in the northern GOM and found that four of the EISs for these facilities evaluated potential cumulative impacts using quantitative approaches. However, these approaches varied in the method used to group facilities for cumulative impact assessment. These groupings are important in the conduct of the cumulative impact assessments because there may be geographic limits of individual stocks for key species. Our review has concluded that it may be appropriate to group facilities geographically for assessment of potential cumulative impacts on a subpopulation of some fish species (e.g., red drum). However, additional information on the population characteristics of the key species is necessary to evaluate the validity of this approach for each individual species. It seems clear that assessments of potential cumulative impacts that group and add up predictions for all facilities the GOM may not be the best approach and that artificial grouping of facilities by regulatory criteria is also inappropriate and irrelevant from an ecological perspective. One should also recognize that assessing cumulative impacts from all eight proposed facilities may be overly conservative and should represent an upper-bounds estimate of cumulative impacts, because it is likely that all proposed facilities might not be built.

Another important consideration is that the cumulative assessments should use consistent metrics to quantify impacts. Based on our evaluation of the fish models (Section 3.2.3), we believe losses, including cumulative losses, should be quantified on an egg-equivalent basis rather than on an equivalent yield basis, and then evaluated using stock assessment models (Section 3.2.3). This approach would ensure consistency between impact evaluations for individual facilities, cumulative impact assessments, and the methods used by fisheries managers to evaluate and regulate impacts on fish populations as a whole.

The potential cumulative impacts assessments have not used consistent methods and uncertainties have not been quantified, nor have the results of the assessments been qualified based on the uncertainties. However, the most recent EISs have taken more comprehensive approaches to the assessment of cumulative impacts. In particular, the draft EIS for the Main Pass Energy Hub facility includes all other facilities then planned in its cumulative impact assessment.

3.3.5 Recommendations

Our recommendations for conducting cumulative impact assessments for multiple OLV facilities in the northern GOM are:

- Use a species-specific approach for grouping facilities appropriately based on the stock structure for the key species. If the stock is considered one Gulf-wide population, potential cumulative impacts should be assessed on a Gulf-wide basis, grouping impacts from all proposed OLV facilities. This would require a review of the stock structure for each key species.

- Use appropriate metrics to quantify potential cumulative impacts. According to our evaluation of the ichthyoplankton models in Section 3.2.3, egg-equivalents are the most appropriate endpoint for estimating potential entrainment impacts, and stock assessment models are the most appropriate approach for evaluating population-level impacts.

- Estimate potential cumulative impacts using low, median, and upper bound estimates of the model input parameters, or by conducting a probabilistic analysis to compensate for and/or quantify uncertainties.

3.4 Adequacy of Proposed Prevention Measures

The DWPA specifies that the Secretary may only issue a license if "the applicant has demonstrated that the deepwater port will be constructed and operated using best available technology, so as to prevent or minimize adverse impact on the marine environment." Therefore, the EISs specify recommended measures to mitigate the potential environmental impacts associated with the construction and operation of the offshore facilities. These mitigation measures also include provisions for the development and implementation of prevention, monitoring, and mitigation plans that will be used to monitor marine fish mortality and develop adaptive management[9] procedures that will allow for modification in the operational design to further minimize environmental impacts. Because of concerns raised in the comments on the EISs with regard to the effectiveness of the proposed mitigation measures and monitoring plans, the EISs were evaluated to determine the adequacy of such measures for mitigating potential fisheries impacts from entrainment and impingement. The questions we sought to answer in our evaluation of the proposed mitigation measures were:

- Do the predicted results of the impact assessments consider the mitigation measures that have been built into the designs and locations of the seawater intake systems?
- Are adequate mitigation measures and monitoring plans in-place to offset potential entrainment impacts?

3.4.1 Summary of Proposed Prevention Plans from the EISs

To minimize the impact of entrainment and impingement, mitigation plans that were included in the project designs provide specifications for intake screen mesh sizes, seawater intake velocities, use of antifouling agents, and the location of intakes and outfalls. Mitigation measures proposed in the EISs to minimize fish mortality from entrainment include:

- Location of facilities offshore, away from spawning areas of commercially important species
- Wedgewire intake screens with a 6.35-mm (0.25-in.) or less slot size to minimize entrainment of larger organisms

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[9] Adaptive management is "a systematic process for continually improving management policies and practices by learning from the outcomes of operational programs" (British Columbia Ministry of Forests and Range 2005).

- Locating seawater intakes at depths near the bottom of the water column where potential entrainment impacts would be minimized, with the ability to change the intake depth or screen mesh size depending on the results of entrainment and impingement monitoring
- Specifications for maximum seawater through-screen intake velocity (0.5 ft/s or less) to allow most fish and some older larvae to avoid the intakes
- Development of prevention, monitoring, and mitigation plans that will be approved by NOAA fisheries and will measure mortality to marine fishes (including ichthyoplankton) associated with seawater intake and facilitate adaptive management decisions.

3.4.2 Ability of Proposed Preventive Measures to Minimize Potential Impacts

We reviewed the literature on wedgewire intake screen mesh size and the vertical distribution of ichthyoplankton in relation to the proposed water intake depths to assess the effectiveness of these proposed mitigation measures in offsetting potential entrainment impacts for the LNG facilities.

3.4.2.1 Wedgewire Intake Screens and Intake Velocity

In the facility EISs, the designs of intake structures are specified as having a screen mesh size of 6.5 mm.[10] Screens of this size are not effective in reducing the entrainment of ELSs of fishes.[11] The ELSs of red drum, for example, range in size from 0.8 to 0.98 mm for eggs and up to 8 mm for larvae (Virginia Tech 1998), and therefore most of these eggs and larvae would not be precluded from entrainment by the 6.5-mm mesh screens. For this reason, the entrainment estimates in the EIS models are based on withdrawal rates for eggs and larvae that are equivalent to the volumetric abundance estimated from ichthyoplankton samples collected as part of the SEAMAP database. The impact assessments assume 100 percent entrainment, without consideration of intake depths and water velocities relative to the vertical distribution of ichthyoplankton. This assumption results in an overestimation of fishery impacts.

Studies conducted for power plants using once-through cooling water systems have shown alternative intake designs using fine-mesh screens can reduce the entrainment rates for eggs and larvae of fishes (U.S. EPA 2005). However, a study by Zeitoun et al. (1981) in Lake Michigan showed there was no significant difference in larval entrainment through two screens (mesh sizes 2.0 and 9.5 mm) and an open pipe, and that egg entrainment was greatest with the 9.5-mm

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[10] With the exception of Gulf Gateway Energy Bridge, where regasification is done on board specially designed vessels using a shell and tube vaporizer, as part of a combined open/closed loop system. Seawater intake for this system is much less and screen size is 21 mm.

[11] Typically, screens need to be 0.5 to 1.0 mm to block the passage of egg and larval life stages (U.S. EPA 2005). The screens to be used on all facilities will block the passage of adult fish.

screen. This suggests avoidance of the intake by larval fishes. The authors estimated approximately 90 percent of the native fish larvae at this site avoided entrainment into the water intake. Therefore, it is reasonable to assume that a 100 percent entrainment rate, regardless of screen mesh size, would overestimate impacts to fisheries.

Laboratory studies have shown that the effectiveness of wedgewire screens in reducing entrainment of fish eggs and larvae is dependent on species because of differences in egg and larval sizes and larval behavior. Amaral et al. (2003) demonstrated species-specific relationships between entrainment and impingement rates that were dependent on through-slot velocity, ambient velocity, and slot size. None of the species used for these tests are important species found in the northern GOM. However, for the tested species, the laboratory studies indicated that entrainment and impingement rates could be reduced to less than 10 percent based on optimization of slot size, velocity, and local hydraulics.

Potential effectiveness of small-mesh screens could be evaluated for key species and intake designs could be optimized to reduce entrainment and impingement rates. There are, however, other additional issues for these fine-mesh intake structures if they were to be considered for the area. Fouling rates in the marine environment would need to be evaluated and the potential for "sweeping effects" due to ambient currents may be less than in riverine or estuarine environments. Another consideration is that smaller screen mesh sizes reduce intake velocities and therefore require a larger screen surface area, which may increase impingement (USCG and MARAD 2005a). According to U.S. EPA (2005), consideration of wedgewire screens with small slot sizes should include *in situ* pilot studies to determine potential effectiveness and identify the ability to control clogging and fouling.

3.4.2.2 Water Intake Depth

The seawater intake depths for the proposed and existing OLV systems in the northern GOM range from 31 ft for Beacon Port to 95 ft for Main Pass Energy Hub. The water intakes are proposed at depths where ideally the potential for entrainment impacts would be minimized. We reviewed the literature on the vertical distribution of red drum ELSs to determine if an optimum depth range exists for locating the seawater intakes to minimize potential entrainment impacts for this species.

Red drum are coastal spawners and tidal currents transport their larvae into estuaries, where they remain through the juvenile stage (Holt et al. 1989 and Rooker and Holt 1997 as cited in Scharf 2000). However, some red drum ELSs occur in offshore waters and the SEAMAP data have shown the presence of red drum larvae in samples collected offshore in the vicinity of the proposed LNG facilities in the northern GOM. We reviewed the literature on the vertical distribution of ELS red drum to determine the depths where their density is greatest, and if they are in fact less abundant at depths of 31 ft or greater.

Lyczkowki-Shultz and Steen (1991) collected ichthyoplankton in the fall of 1984 and 1985 in the north-central GOM, off the Mississippi coast at depths up to 25m (82 ft). They found that larvae were usually more abundant in samples collected in the upper water column (1 to 5 m, or 3 to 16 ft), and that larvae were generally concentrated higher in the water column during daylight hours than at night. There was no relationship between vertical distribution of larvae and temperature, salinity, or prey abundance. Another study in Mississippi Sound showed red drum larvae were more than twice as abundant in the upper half of the water column compared to lower half (Lyczkowski-Shultz et al. 1990, as cited in Lyczkowki-Shultz and Steen 1991). Comyns (1997) studied the distribution of red drum in the north-central GOM reported that most red drum larvae were found at depths less than 18 m (60 ft); however, in certain study years, the highest densities of red drum larvae were found in depths between 18 and 37 m (60 to 120 ft). Holt and Holt (2000) evaluated the vertical distribution of red drum in Aransas Bay, Texas, and found that larvae were more abundant during the day in bottom samples (at bottom depths of 6 m, or 20 ft).

These data suggest that the vertical distribution of red drum is variable, and it appears that red drum ELSs are more abundant in the upper strata of the water column in the open area of the GOM, although they can also be abundant at greater depths in estuaries. Further evaluation of the entrainment data as part of the monitoring programs for the LNG facilities would be required to assess if optimum water intake depths can be determined depending on the site-specific vertical distribution of ichthyoplankton of key fish species at the proposed facilities.

3.4.3 Effectiveness of Prevention, Monitoring, and Mitigation Plans

According to the most recent EIS for a proposed OLV facility, the Main Pass Energy Hub DEIS (USCG and MARAD 2005c, released June 17, 2005), the prevention, monitoring, and mitigation plans would be developed in consultation with NOAA fisheries and other cooperating agencies and would:

- Develop baseline information on fish eggs and larvae in the vicinity of the proposed port for at least 36 months prior to operation
- Develop a monitoring plan that would commence with port operations to assess impacts to ichthyoplankton and would also include monitoring for sodium hypochlorite and use of operational experience to reduce injection concentrations until a minimum effective dose is determined
- Implement “practical and reasonable” methods to minimize water intake and ichthyoplankton entrainment (e.g., different intake screens, location of intakes)
- Provide within 3 years of starting operations a detailed report on the potential impacts of OLV on marine fisheries, relative to the baseline data collected prior to operation of the terminal.

If the monitoring program indicates operational impacts in excess of baseline, mitigation measures will be undertaken including changes to facility operations, aquaculture projects, wetland restoration or other habitat projects (possibly including artificial reef projects), modifications to the water intakes, and the development of research and education programs (USCG and MARAD 2005c). Presuming the prevention, monitoring, and mitigation plans will be carried out as proposed, it is likely that implementation of such plans will adequately offset entrainment impacts. However, review of the site-specific data that will be collected as part of the monitoring programs will be required to test this theory.

3.4.4 Recommendations

Our review of the EISs showed that the assessments do not consider the potential effectiveness of the proposed mitigation measures when developing the entrainment estimates. They instead employ the conservative assumption that 100 percent mortality occurs for all larvae and eggs, estimated per million gallons of seawater intake. Given that mitigation measures and prevention, monitoring, and mitigation plans are in-place for the proposed OLV facilities, the reductions in entrainment as a result of these measures should be considered in the impact assessments and licensing decisions.

Both the EISs and the comments on the impact assessment assume 100 percent entrainment and do not consider the potential effectiveness of the proposed mitigation measures when developing the entrainment estimates (i.e., there are no exclusion credits for mitigation measures in the models). Because the 6.35-mm screens do not reduce entrainment of most fish ELSs, and because site-specific data on the vertical distribution of eggs and larvae are not available, the assumption of 100 percent mortality is conservatively used. However, following the collection of monitoring data, if necessary, the potential effectiveness of employing fine-mesh screens (0.5 to 1.0 mm) could be evaluated for key species and the seawater intake designs could be optimized to reduce entrainment and impingement rates. This would likely require *in situ* pilot studies to determine screen effectiveness and to identify the ability to control clogging and fouling during OLV operations. Further evaluation of the entrainment data collected as part of the monitoring programs would be required to assess if optimum water intake depths can be determined depending on the site-specific vertical distribution of ichthyoplankton of key fish species at the proposed facilities.

4 Conclusions and Recommendations

This review has identified aspects of the impact assessments for LNG facilities—both those conducted by contractors for USCG and comments received from NOAA/NMFS and others—that introduce considerable uncertainty and that systematically overpredict impacts. The methods and assumptions used are not always the most appropriate for estimating potential entrainment impacts on fish populations. The available life history data on key fish species are also inherently variable and result in very large uncertainties when they are used to estimate adult-equivalent impacts. The overall result of these overly conservative and uncertain assessments has been the prediction of potential impacts (based on comparisons of adult-equivalent impacts with fishery landings statistics) that are biased high, and for which upper-bound estimates (e.g., upper confidence limits) are considerably elevated. Overall conclusions of this review are as follows:

- The SEAMAP database is adequate for use in these kinds of assessments. However, the data on fish eggs and larvae are sometimes used inappropriately in the assessments without correctly accounting for systematic seasonal variability. The data analysis techniques used consequently overestimate the number of entrained eggs and larvae, and greatly overestimate the actual uncertainty in those values.

- A mathematically incorrect model has been used underestimates potential survival of eggs and larvae by amounts that vary depending on species and life stage.

- Factors that would reduce entrainment mortality, such as depth exclusion and active avoidance of the seawater intakes, are not accounted for, and tend to increase the overprediction of numbers of eggs and larvae entrained.

- The fish modeling techniques that are used to estimate the potential for fisheries impacts are not based on appropriate endpoints for assessing population-level effects, and are therefore not useful for assessing potential impacts of OLV systems. The modeling approach used in the EISs projects egg and larval abundance through many life stages to fishery harvest weights, an endpoint that is far removed from the data, reliant on highly uncertain life history parameters (stage duration and mortality), and not directly relevant to fish population level effects. Because of flaws in the overall methods and the inherent uncertainties in each step of the assessment, the final estimates of potential impacts on age-1 equivalents or fishery landings of key species have dubious scientific validity.

In summary, there are three fundamental problems of a generic nature in the predictions developed in the EISs:

- The variability and uncertainties associated with how the SEAMAP data are being used overestimates potential impacts and overestimates uncertainty

- The use of erroneous calculation methods and highly uncertain life history parameters in adult-equivalent models produces biased and highly uncertain results, and is inconsistent with stock assessment methods
- The direct comparisons of adult equivalent weights with fishery landing statistics is not a valid comparison and may lead to inappropriate conclusions concerning severity of potential impacts.

Taken as a whole, the data inputs, assumptions, and model approaches used in the EISs tend to significantly overestimate the potential for adverse impacts of facilities—both individual and cumulative. Thus, the EIS estimates of cumulative impacts to fish stocks compared to fishery landings have been taken as reliable predictions of potential impacts, when in fact they are unreliable estimates that are biased high by a factor of approximately 1,750. The EISs do not quantitatively account for all the factors affecting these estimates, and so do not accurately describe the degree of overestimation associated with these values or their overall uncertainty. This is an important omission given the potential for misinterpretation of the EIS findings. As these numbers are transmitted to nonscientific persons, they may be unnecessarily alarming because all of the detailed qualifiers concerning limitations in the underlying data and the inherent uncertainties (and errors) of the methods are omitted.

As written, the EISs present a possible paradox in the overall conclusions concerning potential impacts on fishery resources. Taking the Gulf Landing EIS as an example, the assessment predicted an upper equivalent yield estimate of impacts to red drum that is equivalent to approximately 8.5 percent of GOM total landings (USCG and MARAD 2004a). Although this estimate is presented as an "upper equivalent yield," it can be misinterpreted by resource managers or other stakeholders as a meaningful potential reduction in this important fishery. For example, the NMFS comments on Gulf Landing (NMFS 2005b) claim that equivalent yield impacts compared to Louisiana landings range from 1.4 to 4.3 percent to more than 11 percent under a worst case scenario. Based on the individual model predictions, overall impacts are characterized in the Gulf Landing EIS as "minor adverse impacts" and "are not expected to be significant." Given the errors, uncertainties, and overly conservative assumptions used in these kinds of predictions, the characterization of potential impacts to fisheries in the EISs and by commenters to the EISs is greatly overstated. Moreover, the predicted reductions in the age-1 equivalents as stated in the EISs can be inappropriately compared with any arbitrarily defined fishery weight statistic (e.g., landings for an individual state), thereby greatly inflating the apparent severity of the potential impact. Such comparisons, whether with GOM landings or state landings, are inappropriate because of the inherent uncertainties in the calculation of adult-equivalent weights based only on ELS mortalities.

Given the high level of overprediction in the current EIS fisheries impacts, the EIS narrative conclusions that these would be "minor adverse" impacts are most likely appropriate and would be supported by scientifically valid assessments based on egg-equivalent endpoints. Preventive measures that could further minimize losses of ichthyoplankton can be evaluated following the collection of monitoring data. Some such measures may include the following:

- Location of facilities away from spawning areas of commercially important species
- The use of fine-mesh screens and low intake velocities associated with intake structures
- Optimal depth locations of intakes
- Optimization of chlorination procedures during periods of ichthyoplankton occurrence to minimize mortalities while preventing fouling.

Monitoring programs implemented after facility startup can provide data that will allow more specific and detailed assessments of potential impacts, with results that are both more accurate and more precise than those in the EIS. Modeling approaches using those data should be focused on an egg-equivalent endpoint that is compatible with stock assessment models and that allows integration of potential OLV impacts with other factors influencing fish populations in the Gulf.

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Appendix A

Derivation of the Formula for the Adjusted Survival Fraction

Derivation of the Formula for the Adjusted Survival Fraction

Natural mortality that occurs during a life stage results in a decline in the number of organisms alive during that stage. When the natural mortality rate is constant (e.g., 10 percent of the population per day), the decline follows an exponential function. The formula for this function is shown in Equation A-1, and is illustrated by the curve labeled N(t) in Figure A1.

$$N(t) = N_0 e^{-kt} \qquad \text{Eq. A-1}$$

where:

$N(t)$ = the number of individuals alive at time t
N_0 = the number of individuals alive at the beginning of the life stage
k = the natural mortality rate (day^{-1})
t = time (days).

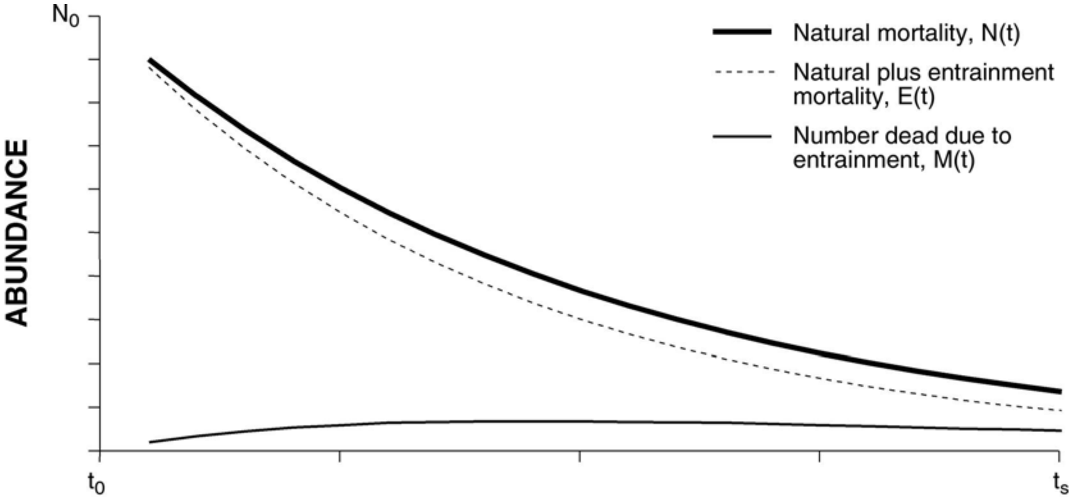

Figure A1.
Relationship between natural mortality and entrainment mortality

The survival fraction is the number of individuals alive at the end of the stage divided by the number of individuals that entered the stage alive. This corresponds to $N(t_s)/N_0$, where t_s is the length of the stage.

When a constant rate of entrainment mortality also occurs during a stage, the total mortality rate is the sum of the natural and entrainment mortality rates. The formula for this function is shown in Equation A-2, and is illustrated by the curve labeled E(t) in Figure A1.

$$E(t) = N_0 e^{-(k+m)t} \qquad \text{Eq. A-2}$$

where:

m = the entrainment mortality rate (day^{-1}).

The number of individuals dying from entrainment at each time is the difference between these two functions. The formula for entrainment mortality as a function of time is shown in Equation A-3, and is illustrated by the curve labeled M(t) in Figure A1.

$$M(t) = E(t) - N(t) = N_0 \left(e^{-(k+m)t} - e^{-kt} \right) \qquad \text{Eq. A-3}$$

The entrainment mortality function, M(t), is the number of individuals that would have lived but for entrainment. Had these individuals lived (i.e., not been entrained), they would have been subject to natural mortality. This natural mortality would reduce the number of individuals that would survive to the end of the stage. Figure A2 illustrates the effect of natural mortality acting on the entrainment mortality function for two example times, t_a and t_b.

Figure A2.
Potential survival of entrained organisms

As illustrated in Figure A2, the number of individuals dying (or potentially surviving) at time t_a is $M(t_a)$. This serves as the initial value, analogous to N_0, for the natural mortality rate. Applying Equation A-1, the survivorship function for organisms dying at time t_a is then as shown in Equation A-4.

$$S(t_a) = M(t_a) e^{-k(t_s - t_a)} \qquad \text{Eq. A-4}$$

The survival fraction for the organisms entrained at time t_a is therefore as shown in Equation A-5.

$$S^*(t_a) = \frac{S(t_a)}{M(t_a)} \qquad \text{Eq. A-5}$$

Considering other times, such as t_b, as well, the overall survival fraction is as shown in Equation A-6.

$$S^* = \frac{S(t_a) + S(t_b) + \ldots}{M(t_a) + M(t_b) + \ldots} \qquad \text{Eq. A-6}$$

The repeated sum in Equation A-6 is equivalent to an integral over the length of the stage. This is represented in Equation A-7.

$$S^* = \frac{\int_{t=0}^{t_s} S(t)dt}{\int_{t=0}^{t_s} M(t)dt} \qquad \text{Eq. A-7}$$

Replacing the functions in Equation A-7 with the equations shown in Equations A-3 and A-4, performing the integration, and evaluating the integrals over the stage length (t_s) produces the result shown in Equation A-8.

$$S^* = \frac{e^{-kt_s}\left(\frac{e^{-mt_s}}{m} + t_s - \frac{1}{m}\right)}{e^{-(k+m)t_s}\left(\frac{1}{k+m} - \frac{e^{mt_s}}{k}\right) - \left(\frac{1}{k+m} - \frac{1}{k}\right)} \qquad \text{Eq. A-8}$$

Equation A-8 is the exact solution for the adjusted survival fraction within a stage, when both the natural mortality rate and the entrainment mortality rate are known.

Attachment 1

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Documents Reviewed

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