Peer Review of Exponent's Analysis of Icthyoplankton Assessment Modeling for Shell's Gulf Landing LNG Terminal Environmental Impact Statement

Report to the Regional Marine Conservation Project

and

Gulf Restoration Network

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1 Introduction

A number of companies that import liquefied natural gas (LNG) to the US have proposed to construct facilities in Gulf of Mexico waters to convert the LNG to a gaseous state. The facilities propose to pump the warm waters of the Gulf of Mexico (GOM) through a heat exchange system to warm the LNG, a process known as open rack vaporization (ORV). The US Coast Guard, responsible for preparing an environmental impact statement (EIS) for each facility, contracted with E2M to model the impacts of LNG ORV on fish in the GOM.

The E^2M report on the modeling (E^2M 2005; Appendix G of the Gulf Landing LLC Deepwater Port License Application EIS) uses available data to estimate the entrainment of eggs and larvae through the LNG ORV system and, assuming 100% mortality, to estimate the impacts of the mortality on fish and fish populations in the GOM. The E^2M study used available ichthyoplankton data collected under the Southeast Area Monitoring and Assessment Program (SEAMAP) between June 1983 and September 2000. This egg and larvae data set is restricted on both spatially and temporal scales and represents six months of the year from June through November (Table G-1; E^2M 2005). In total, only 75 larvae and 26 egg samples were taken within the study area.

The Exponent report evaluated the approaches used in the E^2M report and proposed alternate methods to predict potential impacts of ORV systems for LNG on fishery resources of the GOM.

This report reviews the Exponent report in the context of the methodology of the E^2M analysis.

2 Objectives of the Study

The objectives of this study are to critically review the Exponent and E^2M reports to evaluate (1) the methodology and use of data that led to the Exponent conclusions, and (2) the resulting conclusions of the report. In particular, the authors addressed the following questions:

a) Does Exponent's work and the underlying modeling by E^2M sufficiently incorporate existing uncertainty in early life stage tables for analyzed species? If not, how would such a correction influence potential impacts?

b) Does Exponent's work and the underlying modeling sufficiently correct for bongo net extrusion rates? If not, how would such a correction influence potential impacts?

c) Does Exponent's work correctly develop and apply a seasonal variability correction factor to the E^2M model? How could those corrections influence impacts estimates?

d) Given the absence of an analysis of possible entrainment of eggs and larvae by the outflow plume of the LNG facility, is there existing research that could allow for the creation of an impacts model? If so, how would that model influence the range of potential impacts?

3 Study Approach

MRAG Americas, Inc. (MRAG) based this review primarily on comparing the Exponent and the E^2M reports. MRAG used other material to evaluate methodology of the two reports, but focused on the issues listed in Section 2, Objectives. MRAG obtained information used in the review from internet searches, personal communications, and peer-reviewed publications. We used a NOAA Fisheries preliminary review memorandum of the Exponent report (NOAA Fisheries 2006) to identify ranges of points of view, even though the preliminary findings and conclusions do not represent formal NOAA Fisheries policy. In circumstances where primary reference material was not available, we reference the report in which it was cited. For example, we did not obtain a copy of the EPRI document (2004) that contains methods for extrapolating impingement and entrainment losses to equivalent adults and production foregone because of the high cost ($2,500).

Due to time constraints, it was not feasible to regenerate ichthyoplankton abundance data, presented in the Exponent report (see data summary in Exponent Table 3-1) from original sources. All subsequent analyses and results presented in this review, based on this post-processed SEAMAP data, may contain errors of rounding. This report recalculated survival fractions from the Exponent report using suggestions from NOAA Fisheries.

4 Analysis

Lack of available quality data for assessing the impacts of LNG ORV facilities on marine systems may lead to a use of available data in ways for which they were not intended, and for serious speculations on the application of the data in terms of impacts on living marine resources. No predictions of the impacts can be made with certainty. However, decisions on permitting for ORV facilities require guidance from best available data. The uncertainty inherent in the best available data could lead to impacts ranging from negligible to severe, depending on assumptions, how one deals with the available information, and the level of precaution imposed. The following discussions of this section present MRAG's view on the issues identified in the Objectives (Section 2) and other topics related to these issues.

4.1 Modeling approach

4.1.1 Modeling endpoint

The Exponent report criticizes the approach taken and modeling end-point selected in the EIS (E^2M 2005). The E^2M report estimates adult-equivalent losses in yield using ichthyoplankton assessment models, which are then compared to Gulf fishery harvests. The Exponent report highlights potential weaknesses of the adult equivalent model (Exponent 2005, p. 3-22) to this approach:

- 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 early life stages.
- The comparison to fishery harvest levels does not provide any meaningful information about the potential impacts of ORV facilities on fish populations as a whole.
- The model used contains an error in one formula that results in over prediction of egg and larval mortality.

Exponent recommends expressing the potential entrainment impacts in terms of total equivalent eggs rather than fishery production, and noted that "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." The justifications for hind-casting with an egg-production model endpoint include: 1) a requirement for instantaneous mortality and stage duration parameters only from egg and larval stages rather than for the full life history; 2) no requirement for growth rate and length:age parameters; and 3) compatibility with stock assessment models that use egg production (spawning potential ratio [SPR] and spawning stock biomass per recruit [SSBR]).

Goodyear (1993), in a discussion of SSBR in fishery management, noted that substantial mortality of organisms caused by withdrawal of water for cooling power plants requires evaluation of dependence of recruitment on stock size to determine impacts. Goodyear (C. Phillip Goodyear, NMFS SEFSC (retired), pers. comm.) subsequently recommended that the hind-casting method applied to entrainment losses provides a better assessment of impacts from egg and larval losses on population status. The hind-casting allows use of SSBR and SPR for predicting recruitment changes based on stock size. He concluded that forward projections of adult equivalents do not show a relationship with stock size and do not indicate the importance of loss to the population.

However, unless the proportion of eggs and larvae mortality is a large proportion of the total, the hind-cast results could result as a small proportion of the total uncertainty in spawner-recruit relationships, representing little more than noise in the system.

The validity of the hind-cast methodology does not make forward projection methodology inappropriate. The direct impact of the LNG ORV entrainment is killing existing organisms and preventing their contribution to future production or harvest. Forward projection techniques have been used in diverse circumstances and add a different viewpoint to evaluation of impacts. For example, the US Environmental Protection Agency (EPA) reviewed use of forward projection models of adult equivalence with static life history parameters and without density dependence (EPA 2002). The EPA used these models to calculate age 1 equivalents, lost fishery yield, and lost fish production for several energy facilities that cause impingement and entrainment for cooling purposes. The EPA makes the point that uncertainty may mask population effects, especially if large numbers of individuals are involved; and that direct impacts on individuals often take precedence over population impacts if the populations impacts are unclear. The EPA concluded that the forward projection models are precautionary in nature, especially given the large amount of uncertainty inherent in modeling stock recruitment relationships.

Once a new source of mortality occurs, such as an LNG ORV facility, management procedures could adjust harvest to prevent resource damage. This could involve redefining stock reference points (*e.g.,* minimum spawning stock threshold) or harvest rates to take into account the additional mortality. Scientists at the International Pacific Halibut Commission (IPHC), for example, have developed methods of dealing with pre-recruit mortality (in this case, from bycatch of Pacific halibut in other fisheries) that jointly recognize impacts on stock status and the fishery. The IPHC has no control of halibut bycatch in groundfish fisheries, just as Gulf of Mexico management agencies would have no control of egg and larval entrainment if an ORV facility went into production. In the 1990s, the IPHC exploitation strategy was based on maintaining, on average, an optimum spawning biomass and therefore an optimum egg production, so the logical way to compensate for bycatch was to reduce the commercial halibut quota by an amount just sufficient to result in the same level of egg production as would have occurred had there been no bycatch (Sullivan *et al*. 1994). In the long term, the effect of this adjustment was to maintain the spawning biomass at the level it would have reached if fished at the target exploitation rate with no bycatch. In 1997, the IPHC adopted a new method of handling pre-recruit bycatch in setting quotas. The mortality due to sublegal bycatch was incorporated into the population model that is used to evaluate alternative exploitation rates, so an allowance for sublegal bycatch is contained in the chosen exploitation rate (Clark and Hare 1998).

Accounting for pre-recruit mortality (bycatch) by including that mortality in the population model used to choose the target harvest rate treats that mortality as an integral part of the harvest strategy (Clark and Hare 1998). The effects of all sources of mortality on both biomass and yield are considered simultaneously when choosing a harvest rate that achieves the best balance of their management objectives, which include maintaining a healthy level of spawning biomass along with obtaining a high and stable yield. This approach has proved successful in the Pacific halibut fishery.

4.1.2 Survival modeling

The Exponent report points out that natural mortality and entrainment mortality for eggs and larvae occur simultaneously, and that survival estimates should account for this. The E^2M report assumes that all entrainment mortality occurred at the midpoint of the life history stage. Both equation 1 in the Exponent report and NOAA Fisheries equation 4 (NOAA Fisheries 2006) provide calculations of survival fractions after entrainment that account for continuous entrainment mortality. The NOAA Fisheries equation closely follows the form of total (combined) mortality (Z) equals the sum of fishing (F) and natural (M) mortalities (Z = F + M). As such, we prefer the NOAA Fisheries model.

Table 3.3 in the Exponent report compares survival fractions to the survival fractions calculated in the E^2M report. In all cases, the Exponent survival fractions are less than the survival fractions presented in the E^2M report (however, the Exponent reports uses a survival equation attributed to the E^2M report that differs from the equation actually presented in the E^2M report). We repeated the comparison using the values from the E^2M equation, the values resulting from NOAA Fisheries equation 4, and the range of entrainment mortality values from the Exponent report (see Table 1). The survival fractions calculated with the NOAA Fisheries equation were also lower than the E^2M values, but higher than the Exponent values.

4.2 Data transcription error – Revised

The forward projection of age-1 and adult equivalents is based on the estimated number of eggs and larvae killed by entrainment in an LNG ORV facility. The E^2M report has transcription errors in which red snapper values were switched with bay anchovy values, which could cause errors in the estimated numbers of red snapper larvae present in the system. An initial discrepancy occurs between Tables G-4 and G-5: Table G-4 show low densities of red snapper relative to density of bay anchovy; Table G-5 shows red snapper density over 200 times greater than bay anchovy, suggesting that a switch of bay anchovy and red snapper occurred here[1]. Tables G-9, G-10, G-11 and G-12 are derived from Table G-5 (although, in converting the larval estimates from Table G-11 to eggs in Table G-12, the larval values were transferred directly without conversion to numbers of eggs) and show a switch of red snapper and bay anchovy densities. Subsequent E^2M Tables G-60 through G-73 calculating age-1 losses and adult equivalent losses, however, are consistent with Table G-4 but not with Table G-5.

If analysis of SEAMAP data shows that Table G-4 correctly displays the red snapper and bay anchovy densities, then the calculations in Tables G-60 and following of the E^2M report correctly represent the age-1 and adult equivalent losses. While MRAG was unable to obtain and analyze SEAMAP data for this report, discussions with knowledgeable scientists lead to a conclusion that Table G-4 correctly displays the larval density for red snapper and bay anchovy and that the data switch occurred at Table G-5. Based on this conclusion, we suggest that the E^2M Tables G-61, G-63, G-65, G-67, G-69, G-71 and G-73 appropriately calculate the age-1 and adult equivalent losses under the assumptions for each table.

4.3 Early life history uncertainty

Both the E^2M and Exponent reports acknowledge that life history parameters used in the assessments have considerable uncertainty. E^2M uses both species-specific and extrapolated values from a number of primarily peer-reviewed articles and reports reviewed under the Southeast Data Assessment and Review (SEDAR) process. Exponent uses species-specific values from a contract report (Gallaway 2005) prepared for the Pearl Crossing LNG Terminal Project. In general, peer reviewed articles are preferable to contract reports, and species-specific values are preferable to values extrapolated from other species. For unpublished reports, data that have undergone expert panel review and scrutiny are preferable to data that have not undergone

[1] The original MRAG review attributed the data switch between E^2M Tables G-5 and G-10. As a result, the original review recalculated red snapper age-1 and adult equivalent losses using the data from Table G-5, thereby using bay anchovy density rather than red snapper densities.

such review. For un-reviewed reports with equal scientific credibility, those that provide more precautionary results are preferable to those less precautionary.

On this basis, the results from using the life history tables in the E^2M report are considered more favorable than those presented in the Exponent report. E^2M values, while both species-specific and extrapolated, are mostly peer reviewed, in current use in the NMFS Southeast Region, and more precautionary. The Exponent report values, while species specific, are not peer reviewed, have not undergone local expert review, less precautionary, and outside the range of published values. A review of the life history parameters in the Exponent report seems an appropriate activity for an expert panel, perhaps the Scientific and Statistical Committees of the Gulf of Mexico and South Atlantic Fishery Management Councils, and offers an opportunity to incorporate recent information into the previous analyses.

The E^2M report uses single reported values if no other information were available, and the range of reported values or the upper and lower 95% confidence intervals, if available, as bounds for uncertainty in the egg and larval life history tables. The E^2M report also presents impacts for the range of information available; while an individual range may not fully capture the actual value and range, the aggregate of ranges likely does so.

In addition, the E^2M report provides a sensitivity analysis of using a range of life history and entrainment values:

- Base Life History Table and Average Entrainment Estimate
- Low Larval Mortality and Average Entrainment Estimate
- High Larval Mortality and Average Entrainment Estimate
- Base Life History Table and Upper 95 Percent Confidence Limits
- Base Life History Table and Lower 95 Percent Confidence Limits
- Extreme High Estimate Using Low Natural Mortality and Upper 95 Percent Confidence Limits
- Extreme Low Estimate Using High Natural Mortality and Lower 95 Percent Confidence Limits

While data are insufficient to determine where in the range the true impact values should fall, the sensitivity analysis provides values designated by NOAA Fisheries as ‘likely’ and ‘unlikely’ that decision makers can use to balance uncertainty against impacts.

The Exponent report does not provide sensitivity analyses for the modifications it recommends to the E^2M report. Issues of sensitivity could have included effects of different extrusion rates from plankton nets, effects of different number of points in the moving average of daily larval abundance (although this methodology is wrongly applied – see section 4.5), and effects of variation in life history parameters. Given the Exponent report recommendation for a different model for calculating survival rates (Exponent Equation 1), the sensitivity analysis should also include effects of variation in entrainment survival rates.

4.4 Bongo net extrusion corrections

SEAMAP data have been collected using sampling gear fitted with 0.333 mm nets. It is recognized, however, that this gear is substantially less than 100% efficient. The Exponent report highlights the main ways in which net efficiency is decreased, including loss of organisms through the mesh, active avoidance, and diversion by a pressure head at the net mouth, for example. A range of measures have been adopted by NOAA Fisheries to help compensate for the sampling gear, such as use of flow meters at the foot of the net mouth, for example (NMFS 2006).

The efficiency of the bongo net has been subject to a number of studies (e.g. Houde and Lovdal 1984; Comyns 1997, cited in Exponent report). The available literature indicates that the extrusion rates of red drum larvae in the GOM to be between 5.7 and 8.1, by comparing 0.303 mm and 0.202 mm nets (Comyns 1997). As suggested in the Exponent report, the net efficiency value will actually vary according to species in addition to the form and size of the egg and larvae. However, the E^2M analysis uses a standard extrusion rate of 3 as a conservative estimate to represent both eggs and larvae. It is acknowledged in both the Exponent report and the NMFS preliminary review (NMFS 2006) that if the analysis were to be tailored for individual species, the impacts on red drum should be increased by a factor of two or three.

E^2M uses a generic approach with an overall extrusion rate of 3, which is an appropriate procedure if limited information is available for the species involved. However, species-specific analyses should use a species-specific extrusion rate; the red drum analysis example should use the red drum extrusion factor of 6-8.

Although a species-specific analysis was undertaken for red drum in the Exponent report, they continue to use an extrusion rate of 3. It is stated that their results are "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 [E^2M report]." Moving from an extrusion rate of 3 to an extrusion rate of 6-8 for red drum simply means changing the multiplier used to convert values in Table G-10 to values in Table G-11. Applying species-specific extrusion rates for other case study species – if available – would use the same approach (after correcting the switch of data for bay anchovy and red snapper as discussed in section 4.5). However, lack of information prevents an estimate of the magnitude or direction of making such a change.

4.5 Analysis of the Exponent seasonal variability correction factor

The E^2M and Exponent reports identify the total number of larvae entrained as a key value in the analysis of impacts. The E^2M report approaches this as a problem involving a random sample of values indexed by day. It presented information that demonstrated non-random data. However, after evaluating measures of central tendency, the median, mode, mean, and skewness, the E^2M report determined that the best values to use as estimates for the larval and egg density in the study area are the standard mean and upper and lower 95 percent confidence limits. The Exponent report identifies a systematic seasonal variability in larval abundance overlain on the high sample-to-sample variability typical of plankton tows. To correct for the seasonal variability, the Exponent report uses an 11-day moving average of daily larval density. We conclude that analyzing the larval density in a time-series structure *could be* an appropriate method, but that the Exponent report did not use this approach correctly.

The Exponent report criticizes the E^2M report because the standard mean and confidence intervals "overestimate" the variability. Technically, the criticism is not exactly correct. The variance estimated under the E^2M procedure is likely a fair estimate of the variance of the estimator (the sample mean). A valid criticism would be that this is a poor estimator for the problem.

The "solution" proposed in the Exponent report applies inappropriate statistics. By summing the moving average values (i.e., taking the sum of a sequence of 11 day moving averages) they produce an estimator that is negatively biased for the "total." Essentially, the result is a sum of observations, but the first ten and last ten observations receive weights *less than* 1. Hence, the total they calculate will always be less than the sum of the observations with *equal* weights of 1.

The variance they report is naive and incorrect. Summing the variances of the sequence of 11 day moving averages (based on the report footnote of page 3-16) is wrong. The moving averages they have produced are not independent, so calculation of the variance should include covariance terms to get the variance of their sum. In a situation like this, the covariance terms might well dominate and, if they are positive (which appears true given the plot presented in the report, page 3-15), ignoring these terms will result in a substantial negative bias for the estimated variance.

This problem needs specification of a formal probabilistic structure within which to derive estimators (and a definition of what should be estimated in the first place). An appropriate framework is not totally obvious here. The problem could be put into a time series structure, which is close to what the Exponent report does by using their moving average as a filter (*i.e.,* a smoother). Non-stationary behavior (essentially a non-constant mean) would be a concern but it does not appear that Exponent completely removed mean structure with their moving average (which is typically the goal in such a procedure). Alternatively, one could formulate a structure in which daily values are taken as realizations of independent random variances with non-constant expectation (means). Here, estimating a "total" would be estimating the sum of the means, which might be a suitable framework within which to consider the problem. Regardless, the main point is that the Exponent report does not give the problem any statistical form and progress will be difficult without doing so.

4.6 Entrainment of eggs and larvae in the outflow plume

MRAG could find no studies directly comparable to eggs and larvae in undisturbed water entrained into the discharge plume of the LNG ORV facility. Most studies of mortality at discharge evaluate numbers of live (or dead) individuals collected at the discharge relative to the number observed going into the facility (EPA 2002). However, studies of river plumes into bays or oceans or sewage plumes into bays demonstrate that eggs and larvae concentrate along the boundary of the plume (AIMS 1998, Govoni *et al*. 1989) and subsequently mix with the plume. This suggests that eggs and larvae in ambient water downstream from the LNG ORV outflow will mix with the outflow water at some rate determined by the physical characteristics of the ambient and outflow waters. Mortality and reduced fitness of eggs and larvae would occur if the temperature and biocide concentrations reach sufficient levels of toxicity.

The impact on eggs and larvae of mixing ambient water with outflow water will depend on 1) the initial toxicity of water from temperature (cooling) and biocides, 2) declining toxicity with the dilution rate, and 3) the mixing rate of eggs and larvae from ambient water into the plume. Eggs and larvae from ambient water will experience the highest rates of impacts when mixed with the plume closest to the point of discharge where relative toxicity is highest, compared to eggs and larvae downstream in the plume, due to mixing and dilution. At intermediate distances, the plume will cover a large area but with reduced toxicity and lower impact rates per individual. At some distance from the outflow point, ambient water thoroughly dilutes the plume to the point that no measurable toxicity effects remain.

A simplified model could take the form of a declining function of toxicity with distance from the discharge (from dilution) combined with an increasing function of number of larvae affected with distance from the discharge (as the plume gets larger). Analysts could increase realism and complexity of the model by adding boundary effects to the model to examine mixing of eggs and larvae across the boundary and by adding sub-lethal effects that may reduce fitness and cause delayed mortality. In the absence of specific studies of toxicity on individual species, this approach would require toxicity proxies for species of interest. This approach would also require information on characteristics of ambient water and the plume sufficient to estimate mixing between them.

Constructing an outflow entrainment model would help to determine a level of total egg and larval mortality due to the LNG ORV system. While some mortality due to entrainment of eggs and larvae in the outflow plume seems likely, we cannot speculate on the magnitude and significance of these impacts.

4.7 Other sources of mortality

This analysis focuses primarily on assessing the information provided in the Exponent and E^2M reports. However, other substantial sources of mortality occur on juvenile and adult fish in the Gulf of Mexico by which to compare the potential losses from the LNF ORV facilities. For example, bycatch mortality of red snapper in the Gulf of Mexico ranged from approximately 2 to 3.7 million pounds per year from 2002-2004 (MRAG Americas, unpublished), and the shrimp fishery accounted for the large majority of the bycatch (42-50%). The loss of adult equivalent red snapper in weight from the fishery potentially caused by LNG ORV entrainment (E^2M tables G-61 and following) thus represents a small fraction of the bycatch loss.

Red snapper have been and are currently overfished and undergoing overfishing. The Gulf of Mexico Fishery Management Council recognized the inherent need to reduce red snapper bycatch in the shrimp fishery in 1997 when they approved Amendment 9 to the Shrimp Fishery Management Plan. The purpose of this amendment was to reduce unwanted bycatch of juvenile red snapper in the shrimp fishery and, to the extent practicable, not adversely affect the shrimp fishery. NOAA Fisheries and the Gulf Council continue to work towards bycatch reduction and the current rebuilding plan for red snapper requires additional effort and reductions in bycatch of the shrimp fleet (*Federal Register*: September 7, 2005 (Volume 70, Number 172) http://www.epa.gov/fedrgstr/EPA-IMPACT/2005/September/Day-07/i17713.htm).

5 Conclusions

5.1 Findings

This report reviews the Exponent Consulting Group (2005) critique (referred to herein as the Exponent report) of Appendix G of the Gulf Landing LLC Deepwater Port License Application Environmental Impact Statement (E^2M 2005 – referred to as the E^2M report). We also considered a preliminary review memorandum of the Exponent report that was conducted by NOAA Fisheries (2006) to help identify ranges of points of view. We note that both documents bring professional and critical thinking to the analysis of impacts from liquefied natural gas (LNG) open rack vaporization (ORV) facilities, but also note several conceptual and technical errors in analyses. Both documents present estimates of the number of eggs and larvae entrained and the impacts of entrainment mortality on several case study species, but each uses different approaches to quantify the estimates.

Modeling approach

The modeling approach of the endpoint for analysis represents the primary conceptual difference between the two reports. The E^2M report used a forward projection from the number of dead eggs and larvae to calculate the equivalent number of age-1 fish and subsequently the number (and weight) of adult equivalent losses to the population and the fishery. This approach very likely overestimates the impacts of LNG ORV because it does not take into account compensatory mortality that must occur between the egg and adults stages. However, the approach represents a precautionary upper limit of reasonable impacts because uncertainty may mask population effects, and government regulatory agencies have adopted the approach for impact analysis. The Exponent report used a hind-cast procedure from the number of dead eggs and larvae to calculate the equivalent number of spawning fish that would have produced the dead eggs and larvae. This approach focuses attention on impacts to the population and allows calculation of spawner-recruit effects of the LNG ORV facilities. Both approaches represent valid analytical techniques. Together, these two approaches bracket reasonable impacts from the facilities.

The E^2M report, the Exponent report, and NOAA Fisheries memo described different versions of models to calculate survival fraction of the populations of eggs and larvae subject to entrainment. E^2M assumed entrainment occurred as a pulse, and Exponent and NOAA Fisheries provided for continuous entrainment mortality. We preferred the NOAA Fisheries survival model because it used the familiar concept of additive mortality. Continuous entrainment models showed lower survival fractions than the pulsed entrainment model.

Data transcription errors

Table G-5 of the E^2M report apparently transposed the bay anchovy and red snapper estimates of entrained larvae during the December-May period: the table shows much higher abundance of red snapper than bay anchovy compared with Table G-4. The transposed bay anchovy-red snapper numbers appear in Tables G-9 through G-12, although the calculations of age-1 and adult equivalent losses of Tables G-61 and following appear correctly based on Table G-4.

Early life history uncertainty

The Exponent report used newly-estimated, species-specific life history information that has not (to our knowledge) undergone external review. A panel of local experts, such as the Scientific and Statistical Committees of the Gulf of Mexico and South Atlantic Fishery Management Councils, should review the new values and determine whether they meet the standard of best available information.

Bongo net extrusion corrections

The E^2M report multiplied abundance estimates from plankton tows by a factor of 3 as a generic correction for extrusion rate of larvae from the plankton nets, but acknowledged higher extrusion corrections for some fish (*e.g.,* approximately 6-8 for red drum). The exponent report also notes the higher extrusion rate. Applying species-specific extrusion rates would require only changing the multiplier used to convert densities in E^2M Table G-10 to values in Table G-11 (after correcting the transposed red snapper-bay anchovy data).

Analysis of Exponent seasonal variability correction factor

The Exponent report attempted to smooth the seasonal variability in daily larval abundance with an 11-point moving average of daily catch rates from Southeast Area Monitoring and Assessment Program (SEAMAP) data. While a time-series structure could improve estimation, the moving averages are not independent, the sum of the averages underestimates the true value, and the sum of the variances underestimate true variance. The seasonal variability correction factor used by Exponent is not statistically correct.

Entrainment of eggs and larvae in the outflow plume

Impacts of the outflow plume on eggs and larvae downstream of the LNG ORV facility depend on the initial toxicity of the water and the dilution rate. A simple model could combine declining function of toxicity with distance from the discharge (from dilution) combined with an increasing function of number of larvae affected with distance from the discharge (as the plume gets larger).

Other sources of mortality

Substantial mortality of juvenile and adult fish occurs in the Gulf of Mexico from fishery bycatch, which may provide a scale for the estimated entrainment losses from LNG ORV facilities. For example, the adult equivalent fishery losses for red snapper amounts to a small proportion of the red snapper bycatch mortality, on the order of 2 to 3.5 million pounds annually.

5.2 Sources of uncertainty

SEAMAP data

There are very few data SEAMAP points for larvae (75) and eggs (36) within the study area collected from research cruises since 1982. The low number of sample sizes will inevitably lead to high variance in the results. Confidence limits have been calculated appropriately for small sample sizes in the E^2M report, using the t-distribution and standard error model. In addition, this has only been sampled between June and November, and therefore excludes sampling for half of the year. The results of the E^2M report have been pooled by month to increase the number of samples taken. Although the sampling distribution is variable between each sampling month, September clearly has the most abundant eggs and larvae in the water column. More consideration needs to be given to possibly abundant levels of eggs and larvae during periods that are not sampled. Due to the short duration of the egg stage (1-2 days) it is unlikely that samples correctly reflect the actual number of eggs laid. This was true for the samples obtained in this area, which were 55.8% less than the number of larvae.

Ideally, species should be individually reviewed to calculate more appropriate estimates for each, but this is not possible due to small sample sizes.

Cumulative impacts

The nature of cumulative impacts will depend both on the spatial and temporal distribution of different species and the number and location of additional LNG ORV systems. The reports specified in the Objectives (Section 2) did not specifically address cumulative impacts, and so this report did not. The limited amount of data available restricts decisions whether eggs and larvae are from one stock or part of a much larger area. Matching duration of life stages and potential distance that currents can carry eggs and larvae requires more information on the biological and oceanographic processes.

Ecosystem impacts

The reports specified in the Objectives (Section 2) did not evaluate non-fish species or the predator-prey relationships of the case-study species. We did not address impact on the wider environment, such as the loss of eggs and larvae of key prey species for commercially and recreationally significant species of fish used in study, as well as key species not actively sought in fisheries.

Operational Mechanisms

The design of the LNG ORV facilities was not clear from the reports specified in the Objectives (Section 2). Such key features as intake depth of the facility, the outflow depth, the design and location of screens, for example, will affect the actual entrainment of eggs and larvae.

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Table

Table 1. Effect of using the survival equations 1 (pulse entrainment from E2M) and 2 (continuous entrainment) from the Exponent report (Top) (Exponent Table 3-3) and using survival equation 1 from the Exponent report and equation 4 (continuous entrainment) from NOAA Fisheries 2006 (Bottom)

	k	ts	m	**S***	**Eqn 4, page G-30**	
Stage	Natutal mortality rate (per day)	Stage length (days)	Entrainment mortality	**Exponent adjusted survival rate**	**EIS Estimate**	EIS/Exp. Estimate
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%

Table 1 (Cont.)

	k	ts	m	**S***	Eqn 4, NOAA Fisheries	
Stage	Natutal mortality rate (per day)	Stage length (days)	Entrainment mortality	**Exponent adjusted survival rate**	**EIS Estimate**	EIS/Exp. Estimate
Red drum eggs	0.5	1	0.0001	**0.840**	**0.7707**	92%
Red drum eggs	0.5	1	0.1	**0.839**	**0.7676**	91%
Red drum larvae	0.3	22	0.0001	**0.030**	**0.0090**	30%
Red drum larvae	0.3	22	0.01	**0.029**	**0.0083**	29%
Red drum larvae	0.3	22	0.1	**0.022**	**0.0048**	23%
Red snapper larvae	0.3	27	0.0001	**0.010**	**0.0025**	25%
Red snapper larvae	0.3	27	0.01	**0.009**	**0.0022**	24%
Red snapper larvae	0.3	27	0.1	**0.006**	**0.0011**	18%