Final General Reevaluation Report
and
Final Environmental Impact Statement

on

Hurricane Protection and Beach Erosion Control

WEST ONSLOW BEACH AND NEW RIVER INLET (TOPSAIL BEACH), NORTH CAROLINA

Appendix Q

Larval Entrainment

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Assessment Of Potential Larval Entrainment Mortality Due To Hydraulic Dredging Of Beaufort Inlet

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The larval fish distribution, abundance, seasonality, transport and ingress at Beaufort Inlet has been extensively studied, particularly during the fall-winter period coinciding with the permitted dredging window (see references below). The concentration of fish larvae (all species combined) typically ranges from 0.5 to 5 larvae m^{-3}. The concentration (i.e. abundance) of larvae varies both spatially and temporally over a range of scales. It is therefore important to recognize that not all larvae in the inlet would be vulnerable to entrainment. Larvae are not equally distributed in the inlet as the flow has considerable asymmetry. During flood the bulk of the transport is on the eastern side of the inlet and most larvae enter on that side. Ebb flows containing larvae that were not retained in the estuary are strongest on the west side of the inlet. In addition, many larvae exhibit a vertical migration strategy that facilitates tidal stream transport. That is, larvae are up in the water column during flood and descend to near the bottom during ebb. Such behavior helps to prevent larvae from being flushed back out the inlet.

One can estimate the potential larval entrainment mortality due to hydraulic dredging of Beaufort Inlet using a simple mathematical model that incorporates the following:

C = concentration of larvae
= 0.5 to 5.0 larvae m^{-3}

M = proportion of larvae dying by natural causes every six hours
= 0.0125 (i.e. 5 % d^{-1}) to 0.025 (i.e. 10 % d^{-1})

V = volume of water entrained by dredge (24 h operation)
= 173,299 $m^3\ d^{-1}$ (USACE)

$\mathbf{P_s}$ = spring tidal prism
= 1.42 E8 m^3 (Jarrett, 1976)

$\mathbf{P_n}$ = neap tidal prism
= 1.32 E8 m^3 (Logan, 1995)

P_b = proportion of larvae in the bottom of the water column
= 0.1 to 1.0

P_c = proportion of larvae in the navigation channel
= 0.1 to 1.0

P_r = proportion of larvae retained inside to estuary during ebb phase
= 0.1 to 1.0

E_s = proportion of daily spring tidal volume entrained by dredge
$= V / 2 P_s d^{-1}$
= 0.0006

E_n = proportion of daily neap tidal volume entrained by dredge
$= V / 2 P_n d^{-1}$
= 0.0007

L_s = initial number of larvae within a spring tidal prism
$= C * P_s$

L_n = initial number of larvae within a neap tidal prism
$= C * P_n$

K_{sf} = number of larvae entrained during a single spring tide flood phase
$= (L_s - (L_s * M * 2)) * P_b * P_c * E_s$

K_{se} = number of larvae entrained during a single spring tide ebb phase
$= (L_s - (L_s * M * 2) - K_{sf}) * P_b * P_c * P_r * E_s$

K_{nf} = number of larvae entrained during neap tide flood phase
$=(L_n - (L_n * M * 2)) * P_b * P_c * E_n$

K_{ne} = number of larvae entrained during neap tide ebb phase
$= (L_n - (L_n * M * 2)- K_{nf}) * P_b * P_c * P_r * E_n$

K_s = absolute larval entrainment mortality d^{-1} during spring tide
$= (K_{sf} + K_{se}) * 2$

Z_s = percent larval entrainment mortality d^{-1} during spring tide
$= (K_s/L_s*2)*100$

K_n = absolute larval entrainment mortality d^{-1} during neap tide
$= (K_{nf} + K_{ne}) * 2$

Z_n = percent larval entrainment mortality d^{-1} during neap tide
$= (K_n/L_n*2)*100$

Mortality due to entrainment was simulated 10,100 times for each level of natural mortality (i.e. 5% d^{-1} and 10% d^{-1}) during both spring and neap tidal conditions by systematically varying $\mathbf{C}$, $\mathbf{P_b}$, $\mathbf{P_c}$, and $\mathbf{P_c}$ over the ranges outlined above using SAS Version 8.2 (SAS Institute Inc., Cary, NC). The results depicting the distribution of outcomes are shown below and include the minimum, maximum and mean impact levels as well as the 10%, 25%, 50% (median), 75% and 90% quantiles.

	Natural mortality 10 % d^{-1}				Natural mortality 5 % d^{-1}			
	$\mathbf{K_s}$ No.	$\mathbf{Z_s}$ %	$\mathbf{K_n}$ No.	$\mathbf{Z_n}$ %	$\mathbf{K_s}$ No.	$\mathbf{Z_s}$ %	$\mathbf{K_n}$ No.	$\mathbf{Z_n}$ %
min	914	0.0006	991	0.0008	925	0.0007	1004	0.0008
max	1660902	0.1170	1801169	0.1365	1682195	0.1185	1824261	0.1382
mean	246426	0.0316	267246	0.0316	249585	0.0320	270672	0.0373
10 %	16282	0.0036	17658	0.0042	16490	0.0037	17884	0.0043
25 %	48845	0.0070	52973	0.0082	49471	0.0071	53651	0.0083
50 %	132906	0.0239	144136	0.0278	134610	0.0242	145984	0.0282
75 %	376763	0.0579	408595	0.0676	381594	0.0587	413833	0.0684
90 %	657882	0.0632	713472	0.0737	666316	0.0640	722619	0.0746

What is quite apparent is that both $\mathbf{Z_s}$ and $\mathbf{Z_n}$ (i.e. the percentage of the daily flux of larvae entrained) are very low regardless of larval concentration and the distribution of larvae within the channel. Under the worst-case scenario where the dredge operates 24 h d^{-1}, all larvae are in the navigation channel, on the bottom, and with poor retention in the estuary following flood stage, the maximum percentage entrained barely exceeds 0.1 % d^{-1}. Most of the simulated scenarios (see the 90 % quantiles) indicate the percent entrainment mortality to be less than 0.06 to 0.07 % d^{-1} with over half falling below 0.03 % d^{-1} (see 50 % quantile). The actual number of larvae entrained however, can range from as few as 914 up to over 1.8 million depending on the initial concentration of larvae within the tidal prism.

This simple analysis of the potential entrainment impacts to larvae could be further refined by stochastically varying the spatial and temporal concentration of larvae and their positions within the water column, but, based on the results presented here, such effort is not required to achieve a useful first approximation of the level of impact to the resource. Because the estimated entrainment mortality, even under the worst-case scenario, is minimal (0.1 % d^{-1}), it seems reasonable to conclude that while any larvae that are entrained will certainly be killed, it is likely that the impact at the population-level would be insignificant.

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