Public Workshop (9/5-6/12)
Bay-Delta Workshop 1
Deadline: 8/17/12 by 12 noon

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
REGION IX
75 Hawthorne Street
San Francisco, CA 94105-3901

August 17, 2012

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SWRCB Clerk

VIA ELECTRONIC SUBMISSION AND MAIL

Jeanine Townsend
Clerk to the Board
State Water Resources Control Board
P.O. Box 100
Sacramento, California 95812

RE: Bay-Delta Workshop 1 – Ecosystem Changes and the Low Salinity Zone
Dear Ms. Townsend:

EPA is providing comments in response to the State Water Resources Control Board's ("Board's") notice dated June 22, 2012, in which the Board presented the schedule for a series of workshops on particular topics associated with its review and potential revision of the 2006 Water Quality Control Plan for the San Francisco Bay/Sacramento-San Joaquin Delta Estuary (Bay-Delta Plan). This letter addresses the topics to be discussed in the first workshop, Ecosystem Changes and the Low Salinity Zone (LSZ), and responds to the questions the Board posed in the June 22, 2012 notice. We also include some preliminary recommendations for consideration as the Board undertakes modification of the Bay-Delta Plan. Our comments build on previous EPA input on the Board's review of the Bay-Delta Plan (see letters of April 24, 2012; February 9, 2012; and March 19, 2009).[1]

What additional scientific and technical information should the State Water Board consider to inform potential changes to the Bay-Delta Plan relating to ecosystem changes and the low salinity zone that was not addressed in the 2009 Staff Report and the 2010 Delta Flow Criteria Report?

A considerable amount of relevant technical work has been completed since the Board released the 2009 Periodic Review and the 2010 Flows Report. This work is focused on explaining the Pelagic Organism Decline (POD), describing the historical ecology of the Delta, improving physical models of the Bay Delta, and/or improving equations that estimate the impact of aquatic habitat variables on abundance of aquatic life. There have also been three peer reviews by a National Research Council committee evaluating the scientific foundation for actions intended to protect the ecological integrity of the Delta and provide for a sustainable water supply.[2] We

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[1] *Available at* www.epa.gov/sfbaydelta/activities
[2] National Research Council (2012) Sustainable Water and Environmental Management in the California Bay-Delta *available at* http://www.nap.edu/catalog.php?record_id=13394; National Research Council (2011) A Review of the Use of Science and Adaptive Management in California's Draft Bay Delta Conservation Plan, *available at* http://www.nap.edu/catalog.php?record_id=13148; National Research Council (2010) A Scientific Assessment of Alternatives for Reducing Water Management Effects on Threatened and Endangered Fishes in California's Bay Delta, *available at* http://www.nap.edu/catalog.php?record_id=12881.

assembled an annotated bibliography of relevant technical studies that have been published in peer reviewed scientific literature or reports produced for natural resource agencies since 2010. This information is contained in Attachment A of this letter.

Below, we briefly describe several conclusions that emerge from recent work and build upon the existing technical work and monitoring from the last several decades in the Bay-Delta.

1. ***X2 is a valid foundation for water quality standards that protect aquatic life.***

   Recent technical studies and reports support using the salinity gradient and its indicator measurement (X2) for water quality standards that protect aquatic life in the estuary. [3] Despite changes to the composition of the aquatic community, the X2 relationships remain significant. We recognize that biological, physical, and/or chemical mechanisms that produce the correlations between X2 and abundance of pelagic organisms are not fully understood and that recent life-cycle modeling[4] suggests food limitation may be a stronger determinant of abundance than flow, as estimated by X2, for at least one of the pelagic species in the Delta. At the same time, it is worth noting that food availability is determined, in part, by flow. The diversity of organisms responding to annual changes in X2 suggests that multiple functions of freshwater flow are responsible for producing the X2-abundance statistical relationships. Freshwater flow variables that have the tightest relationship to abundance may be different for each species, life stage and season. The National Research Council recognized this and concluded that although the mechanisms producing the X2-abundance relationships are hypothetical, the statistical relationships reported in many studies and papers show that the abundance of a number of species at different trophic levels is higher when X2 is lower (further downstream).

2. ***Historically and recently, the LSZ was commonly located west of Chips Island (X2 less than 75 km).***

   An improved understanding of the historical ecology and salinity gradients in the Delta supports the primary assumptions behind X2-based water quality standards. The X2 approach is based on the assumption that protecting aquatic life is optimized by attempting to mimic the natural hydrograph. Recent work describing the historical ecology of the Delta

[3] National Research Council (2012) Sustainable Water and Environmental Management in the California Bay-Delta (*available at* http://www.nap.edu/catalog.php?record_id=13394) ; US EPA (2011) Advance Notice of Proposed Rulemaking for Water Quality Challenges in the San Francisco Bay/Sacramento-San Joaquin Delta Estuary. *Available at* http://www.epa.gov/sfbay-delta/anpr.html; Kimmerer, W. J. 2002. Effects of freshwater flow on abundance of estuarine organisms: Physical effects or trophic linkages? Marine Ecology Progress Series 243:39-55; Kimmerer, W. J., E. S. Gross, and M. L. MacWilliams. 2009. Is the response of estuarine nekton to freshwater flow in the San Francisco Estuary explained by variation in habitat volume? Estuaries and Coasts 32:375-389, and MacNally, R., J. R. Thomson, W. J. Kimmerer, F. Feyrer, K. B. Newman, A. Sih, W. A. Bennett, L. Brown, E. Fleishman, S. D. Culberson, and G. Castillo. 2010. Analysis of pelagic species decline in the upper San Francisco Estuary using multivariate autoregressive modeling (MAR). Ecological Applications 20: 1417–1430.

[4] Maunder, M.N, and R.B. Deriso. 2011. A state–space multistage life cycle model to evaluate population impacts in the presence of density dependence: illustrated with application to delta smelt (*Hypomesus transpacificus*). Canadian Journal of Fisheries and Aquatic Sciences 68:1285–1306; Miller, W.J., B.F.J. Manly, D.D. Murphy, D. Fullerton, and R.R. Ramey. 2012. An investigation of factors affecting the decline of delta smelt (*Hypomesus transpacificus*) in the Sacramento-San Joaquin Estuary. Reviews in Fisheries Science 20:1-19.

suggests that the Delta may have been a freshwater system protected from salt water intrusion by a large area of wetlands, a complex drainage network with high drainage density, and freshwater lakes. Historical ecology of the Sacramento-San Joaquin River Delta (Delta) shows that salinity distributions in relation to flow were very different before the deepening of channels in the western Delta, as shown by Robin Grossinger in his presentation at a 2012 EPA workshop.[5] Large shallow sandbars blocked the upstream movement of salt water, maintaining the freshwater character of the Delta east of Chipps Island almost regardless of changes in flow. This suggests that X2 was rarely greater than 75 km prior to modifications that simplified channels and eliminated water-retaining habitats like wetlands and floodplains. As recently as the 1920s, salinity records indicate that Suisun Bay and Marsh were fresh for most months in most years.

3. ***X2 values between 60 and 74 km are protective of LSZ habitat and X2 values greater than 80 km are not protective of LSZ habitat.***

Modeling advances provide three-dimensional estimates of the location and size of the low salinity zone. When the concept of X2 as a regulatory parameter was developed in 1992, modeling the salinity distribution of the estuary (the LSZ) was one-dimensional. The LSZ was represented by a line (a one-dimensional graphic) on a map showing where the isohaline of 2 practical salinity units was located at a specific distance (a one-dimensional measure) from the Golden Gate Bridge. Today, three-dimensional models of the low salinity zone are available that allow us to estimate LSZ area (two-dimensional measure), volume (three-dimensional measure) and connectivity to adjacent habitats. A simple illustration of information gained through a new three-dimensional model (UnTRIM) of the LSZ is reflected in the attached 'flip-book.' The flip-book shows how the area of the low salinity zone expands at different X2 locations and how the area of the LSZ connects with other habitats and physical features of the estuary.

The maps in the attached flip-book and values in Table 1 illustrate that areal quantity and quality of the LSZ are maximized between X2 values of 60 and 74km and minimized at values of X2 that are greater than 80 km. Table 1 shows that the size of the LSZ is maximized when X2 is 60-74 km. Pages13-15 of the attached flip-book show that the locations of X2 between 60 and 74 km range from the shallow areas of Suisun Bay and Suisun Marsh to Grizzly and Honker Bays. These areas, especially Suisun Bay shallows and Suisun Marsh, are characterized by important habitat elements such as turbidity and food. Recent documents from BDCP, using results of models from Maunder and Deriso for delta smelt suggests that marsh productivity is a vital food resource and that turbidity is a vital aspect of pelagic habitat.[6]

Similarly, we can see that quantity and quality of LSZ habitat are minimized at X2 values greater than 80 km. Pages 18-22 of the flip-book and Table 1 show diminishing LSZ size and access to turbidity and food resources as X2 increases from 80 to 85 km. In this location the LSZ is located in the narrow, armored, channels of the Delta characterized by

[5] Workshop materials, as well as summaries prepared by EPA staff and by the workshop facilitator, have been submitted to the Board, and are available online at www.epa.gov/sfbaydelta/activities.

[6] Maunder, M.N, and R.B. Deriso. 2011. A state–space multistage life cycle model to evaluate population impacts in the presence of density dependence: illustrated with application to delta smelt (*Hyposmesus transpacificus*). Canadian Journal of Fisheries and Aquatic Sciences 68:1285–1306

low quality habitat elements (e.g., food and turbidity). The LSZ is completely disconnected from areas characterized by high turbidity and food when X2 is greater than 85 km. Analysis of the historical record shows that X2 values greater than 80km were rare except during droughts. This information suggests that X2 values greater than 80 km provide little protection of the quantity and quality of the LSZ for aquatic life.

Table 1. Hectares of low salinity habitat for different values of X2. Shaded section is range of X2 data used in the Water Quality Control Plan.

X2 (km)	Salinity (PSU)					Total (hectares)
	1-2	2-3	3-4	4-5	5-6	
	Hectares of low salinity habitat					
59	778	466	357	438	143	2183
60	4736	1353	439	433	296	7257
65	4107	1926	752	545	373	7703
74	2227	2924	1742	1180	1067	9139
81	1337	828	580	1284	884	4914
85	1587	820	815	575	464	4262
90	1150	1008	799	698	654	4308

*X2 are daily averages generated from an 18-month simulation from April 1994 to September 1995. Days were selected to provide representative positions for a given X2.

Identifying the habitat elements that have the greatest effect on LSZ species abundance at values of X2 between 60 and 74 km may be informative for improving water management in the estuary. The difference in water cost associated with these X2 values is considerable. Therefore, it would be useful to determine which habitat variable has the greatest impact on abundance when LSZ habitat conditions are favorable. For example, the freshest part of the LSZ (salinity of 1-2 PSU) is maximized when X2 is 60-65 km, however total area of the LSZ is maximized when X2 is equal to 74 km. Results from ongoing analyses focused on identifying winter through spring flow levels that produce population growth are likely to emerge during the Phase II update to the Bay-Delta Plan. This kind of information will improve our understanding of population responses to different LSZ habitat elements such as gravitational circulation, turbidity, and food availability and subsequently help regulators and planners optimize aquatic life protection.

4. *Invasive species can be managed by flow and salinity*

The Bay-Delta has been identified as the most invaded ecosystem in North America. Invasive species work completed in 1995 showed some invasions occur with extreme salinity events (e.g., Suisun Bay annual mean salinity of 5 ppt) and identified substantial negative ecosystem and economic impacts from these invasions.[7] New analysis shows that since the late 1970s increasing water exports, particularly during drought conditions, produced waves of invertebrate invasions that have profoundly changed the ecological communities of Suisun Bay.[8]

[7] Andrew N. Cohen and James T. Carlton. NONINDIGENOUS AQUATIC SPECIES IN A UNITED STATES ESTUARY: A CASE STUDY OF THE BIOLOGICAL INVASIONS OF THE SAN FRANCISCO BAY AND DELTA. 1995 Report to the U.S. Fish and Wildlife Service. *Available at http://nas.er.usgs.gov/Publications/SFBay/sfinvade.html*

[8] Winder M, Jassby AD. 2011. Shifts in zooplankton community structure: implications for food web processes in the upper San Francisco Estuary. Estuaries and Coasts 34: 675-690.

Drought conditions and increasing exports are associated with higher average X2 values and reduced X2 variability between years. Winder et al (2011)[7] conclude that increased water diversion at times of decreased water availability exacerbated the effects of post-1960 droughts by further reducing freshwater inflow. Amplifying outflow reductions during a drought increased drought severity and allowed unusually extreme salinity intrusions and invertebrate invasions. These conditions intensified benthic grazing on native invertebrates allowing invasive invertebrates to colonize. The authors suggest that "estuarine ecosystem management consider synergistic effects of extreme events with habitat perturbation when assessing invasion risks to coastal ecosystems."

One invasive species that is very likely to invade and become a problem in the near future are Dreissenid mussels, commonly referred to as quagga and zebra mussels. A 2011 report by DWR used water chemistry to predict the future distribution of these mussels in the state.[9] That report suggests that impacts will be greatest south of the Sacramento River because the calcium levels and pH of Sacramento River water are inadequate to support shell-building by these animals. In San Joaquin River waters, impacts are more likely and should be anticipated now, before the problem becomes critical. Based on experience gained in the invasion of these mussels into other North American waters, dreissenid mussels will affect phytoplankton growth in freshwater in much the same way that the Potamocorbula invasion affected phytoplankton growth in low salinity waters.

5. LSZ standards should be protective in all months and years

Results from the first Fall Low Salinity Habitat (FLaSH) studies presented at the 2012 Interagency Ecological Program[10] described information about the size and location of the LSZ in the fall months and delta smelt responses. The FLaSH studies represent the first synthesis of data collected and analyzed as part of the adaptive management program required by the United States Fish and Wildlife Service (USFWS) Biological Opinion on CVP/SWP operations.

The FLaSH studies compare the size and location of the LSZ in the fall of 2006 and 2011 to delta smelt responses in these years. The comparisons suggest that objectives intended to protect the LSZ and resident Delta fishes should be year-round, not just in certain seasons. The LSZ is protected in the spring by flow objectives in the WQCP. These objectives are intended to protect the spring spawning period for delta smelt and other fishes. However, if habitat conditions are poor in the other seasons, juveniles will not survive to become adults that reproduce.

Results from the FLaSH studies show that delta smelt responses such as growth, survival, fecundity, recruitment and other biological metrics were higher in 2011 when average monthly X2 from September to December was 75 km. Delta smelt responses were lower in 2006 when average X2 from September to December was greater than 80 km. This

[9] Claudi, R and K.Prescott_2011 Examination of Calcium & pH as Predictors of Dreissenid Mussel Survival in the California State Water Project, *available at*: http://www.water.ca.gov/environmentalservices/docs/Claudi_Prescott_2011_Examination_of_Calcium_pH_as_Predictors_of_Dreissenid_Mussel_Survival_in_the_CA_SWP.pdf.

[10] http://www.water.ca.gov/iep/docs/041812agenda_abstracts.pdf

suggests that favorable 2006 spring conditions were not sufficient to protect the delta smelt population throughout the year because delta smelt adults could not survive with the poor LSZ quantity and quality (X2 greater than 85 km) conditions present in the fall of 2006. Similarly, 2011 shows that having higher quality and quantity of LSZ habitat in the fall supported the adult delta smelt population.

What changes to the Bay-Delta Plan should the State Water Board consider to address existing circumstances and changing circumstances such as climate change, invasive species, and BDCP?

1. ***Use existing processes to address BDCP.***

   The Clean Water Act triennial review process, when combined with a robust, performance driven monitoring program, allows flexibility to address changes in the Delta from climate change, and/or infrastructure changes such as the BDCP. In addition, the Board will revisit SWP and CVP operations when BDCP representatives submit an application for a change in the point of diversion as required by the Porter Cologne Act and the 2009 Delta Reform Act.[11] At this time, new information or changed circumstances can be evaluated for their impact, if any, on beneficial uses and the regulatory framework used to protect them. EPA and the Board have been collaborating on development of the Delta Regional Monitoring Program. Water quality and aquatic life data collected by this program, along with the IEP and other data sources, should be used to inform future decisions that respond to future changes.

2. ***Use a range of climate change predictions for hydrology variables in long term analyses of Board actions.***

   We recommend that the Board work with DWR and other partners to develop long-term forecasts of water supply, water demand, sea level rise, and flood risk based on the range of anticipated climate change impacts to these hydrology variables.[12] The State of California, especially the Department of Water Resources, has done groundbreaking work evaluating potential likely changes to water resources caused by climate change. Many of the analyses underway for BDCP and updating the WQCP make assumptions about long term precipitation patterns, hydrology, and water demand. These assumptions should reflect the range of current scientific predictions regarding precipitation patterns, hydrology, sea level

[11] 85086(c)(2) Delta Reform Act (2) Any order approving a change in the point of diversion of the State Water Project or the federal Central Valley Project from the southern Delta to a point on the Sacramento River shall include appropriate Delta flow criteria and shall be informed by the analysis conducted pursuant to this section. The flow criteria shall be subject to modification over time based on a science-based adaptive management program that integrates scientific and monitoring results, including the contribution of habitat and other conservation measures, into ongoing Delta water management.

[12] "Storage facilities in the Sacramento-San Joaquin system were designed based on precipitation and streamflow data of the historical period of record (since the late 1800s). The assumption that past climate is a reasonable approximation of the future is no longer valid." National Research Council (2012) Sustainable Water and Environmental Management in the California Bay-Delta, *available at* http://www.nap.edu/catalog.php?record_id=13394; Milly, P. C. D., J. Betancourt, M. Falkenmark, R. Hirsch, Z. W. Kundzwicz, D. P. Lettenmaier, and R. Stouffer. 2008. Stationarity is Dead: Whither Water Management. Science. 319: 573-574; National Research Council. 2007. Colorado River Basin Water Management. Washington, DC: National Academies Press as quoted in NRC (2012).

rise, and water demand in California rather than merely project historical or current conditions. [13]

These long-term forecasts should be used to inform Board decisions about updating water quality standards. This is consistent with Delta Reform Act requirements for BDCP which include estimating "[t]he potential effects of climate change, possible sea level rise up to 55 inches, and possible changes in total precipitation and runoff patterns on the conveyance alternatives and habitat restoration activities considered in the [EIR]."[14]

What changes to the Bay-Delta Plan should the State Water Board consider based on the above information?

As the Board develops alternatives for updating Delta water quality standards, EPA offers the following suggestions:

1. Develop and evaluate alternatives for water quality standards based on recommendations in the 2010 Delta Flow Criteria Report and DFG's "Quantifiable Biological Objectives and Flow Criteria for Aquatic and Terrestrial Species of Concern Dependent on the Delta." These documents identify unimpaired flows necessary to meet the narrative objectives of halting fish population decline and increasing populations of native species as well as species of commercial and recreational importance. We suggest that the Board use these narrative objectives as selection criteria for new or modified water quality objectives designed to protect aquatic life.

2. Compare percent unimpaired flows (UIF) recommended in the 2010 Delta Flow Criteria Report to percent UIF and fish abundance in the early seventies. This comparison will inform how well the recommended percent UIF would comply with the Board's anti-degradation policy. Another informative exercise would be to compare percent unimpaired flows in the late-1990's (a time when abundance of many fish species was improving) to the unimpaired flow recommendations in the Board's 2010 Flows Report. This comparison should indicate how effective the recommended unimpaired flows may be at achieving the goals of halting population decline and beginning population recovery for many species. These comparisons should be done for all months.

3. It appears the Board is considering using a percentage of UIF approach for modifying estuarine standards. The Board believes the UIF approach more closely reflects variation in the natural hydrograph. UIF avoids wide ranges of unimpaired flows determined by the specific hydrology of a month or season and the coarse division of the hydrograph into five water year types that can lead to step-wise changes in flow requirements.[15] We support the UIF approach but note that a UIF approach is valid only to the extent that the resulting flows protect essential habitat elements such as salinity, temperature, nutrient loads, turbidity, and estuarine hydrodynamics, as well as the composition, abundance and distribution of food.

[13] Climate Change Characterization and Analysis in California Water Resources Planning Studies (DWR, 2010)
[14] Cal. Water Code Section Section 85320[b][2][C].
[15] State Water Resources Control Board. 2010. Development of flow criteria for the Sacramento-San Joaquin Delta Ecosystem. Resolution No. 2010-0039.
http://www.swrcb.ca.gov/waterrights/water_issues/programs/bay_delta/deltaflow/docs/final_rpt080310.pdf;

The Board should connect percent unimpaired flows (UIF) to the physical or chemical variables that directly affect beneficial uses and are measurable in the field. For example, salinity or temperature may directly affect the aquatic resource (e.g., fish, invertebrate, algae) and are readily measurable. In some cases, a regulatory parameter, such as the Net Delta Outflow Index, may serve as a surrogate for more detailed analytical tools, but the linkage to measurable field parameters that relate to the protected beneficial use should be explicit and scientifically sound. This is approach equivalent to the 'functional flows' approach to identifying flows needed to support aquatic life described by the UC Davis Delta Solutions Group.[16]

4. EPA recommends the Board anticipate likely invertebrate invasions during drought years by adopting a larger percentage UIF in drought years and developing alternative methods for meeting water quality standards in the event of invasions. EPA recommends the Board protect aquatic resources by mandating immediate adoption of suitable fish screens in the south delta and/or developing alternative methods for meeting water quality standards in the event of invasions, probably by further restricting the number of fish entrained once the mussels impair the present screens. The impacts of dreissenid mussels may require changes in flows that protect estuarine and freshwater habitats, but suitable responses will have to rest upon site specific studies of impacts once they have invaded. Implementation of such studies should be identified as a priority now so that baseline data can be gathered and increased monitoring efforts can be ready for immediate response. Dreissenid invasion is likely to be fast and severe, and the scientific and management response will need to be similarly rapid and intense.

5. Consider refining several aspects of the X2 standard. First, work recently done by Dr. Mueller-Solger illustrated that the calculation used by the export project operators to interpolate X2 for purposes of compliance contained a bias that tended to underestimate the effect of flow on X2.[17] The amount of water involved in the bias appears to be small, but the ability to compare field data with operational and modeling outcomes was identified. This analysis should be reviewed to see if changes in the implementation of the X2 standard are needed.

   Second, reevaluate the Roe Island trigger for the X2 standard. The Roe Island trigger was adopted so that the duration of the low salinity zone in Suisun Bay (X2 < 65) was comparable to what it would have been in the early 1970s, a period of relatively beneficial conditions for aquatic resources. The Roe Island X2 standard is 'triggered' if X2 moves west of Roe Island (X2 < 65) in the spring months. Evidence submitted by the Bay Institute to the Board in their earlier evidentiary hearings suggested that the Roe Island trigger has been manipulated through project operations, minimizing the frequency of triggering the standard and months with X2 < 65. This undermines the frequency of the low salinity zone in Suisun Bay (X2 < 65) as well as the duration. The Board should evaluate the continued need or usefulness for the trigger and consider modifications to the Roe Island standard that place

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[16] Delta Solutions Group (2010). "On Developing Prescriptions for Freshwater Flows to Sustain Desirable Fishes in the Sacramento-San Joaquin Delta" *available at* http://www.waterboards.ca.gov/waterrights/water_issues/programs/bay_delta/deltaflow/docs/intro_fish_flows_for_the_delta_15feb2010.pdf

[17] Notes on Estimating X2 with DAYFLOW. Produced for EPA's Technical Workshop on Estuarine Habitat in the Bay Delta Estuary (March 27, 2012) *available at* www.epa.gov/sfbaydelta/activities. Scroll down and click on Sacramento-San Joaquin Delta Water Quality Standards to reveal the collapsed list identical to the one above

the LSZ in Suisun Bay (X2 < 65) at a frequency and duration that are comparable to periods of time that were (relatively) beneficial for aquatic life.

Third, reconsider the current fixed February 1 start date for the spring X2 measures consistent with recommendations in the Board's 2010 Delta Flow Criteria Report and CDFG's "Quantifiable Biological Objectives and Flow Criteria for Aquatic and Terrestrial Species of Concern Dependent on the Delta." Intensive studies of both salmon migration downstream and smelt migration upstream highlight the influence of first flush conditions that change salinity, turbidity and flow conditions in the estuary. The Board should evaluate either: (a) stating the start of the protective period in terms of some real-time measure of 'first flush,' or (b) stating the start of the protective period as a fixed date, but making that fixed date earlier than February 1 so that it is more likely to reflect the arrival of the first flush.

6. Monitoring requirements that support evaluating effectiveness of water quality standards need to be included in modifications to the WQCP and orders that implement WQCP. Identifying performance measures for protected uses and numeric goals are important metrics needed to assess the effectiveness of standards. One example of an analytical framework linking each requirement (e.g., water quality objective) to a measurable ecosystem response and how the ecosystem response indicates progress toward a Basin Plan goal is in the draft *Framework for a Unified Monitoring, Assessment and Reporting Program (UMARP) for the Bay-Delta 2010 Report.*[18] This framework provides an example of how to link requirements (e.g., water quality objectives) to measurable ecosystem responses and then evaluate the ecosystem response for progress toward Basin Plan goals. The Delta Regional Monitoring program should be built and used to synthesize and publicize monitoring data collected pursuant to the Bay-Delta and Sacramento-San Joaquin Basin WQCPs and their implementing orders.

Thank you for this opportunity to provide written comments. EPA looks forward to the upcoming workshops. If you have any questions about our comments or about the material attached, please contact me at (415) 972-3472.

Very truly yours,

Original signed by

Karen Schwinn
Associate Director
Water Division

[18] Luoma et al (2011) Draft Framework for a Unified Monitoring and Assessment Program for the Bay-Delta for the Bay Delta 2010 Report *Available at* http://www.waterboards.ca.gov/mywaterquality/monitoring_council/estuary_workgroup/docs/2011/umarp_report022111.pdf

Appendix A: Annotated Bibliography of Peer Reviewed and other Technical Studies of SF Bay Delta Estuary, low salinity zone, and aquatic life.

This annotated bibliography is responsive to the first question the Board posed in the June 22, 2012 notice,[1] "What additional scientific and technical information should the State Water Board consider to inform potential changes to the Bay-Delta Plan relating to ecosystem changes and the low salinity zone that was not addressed in the 2009 Staff Report and the 2010 Delta Flow Criteria Report?"

Important Notes:

1. This is a live document continually being updated. EPA will provide updates to State Board staff as we complete them.
2. The information and citations listed below focus on ecosystem changes, low salinity zone, hydrology, flow, and aquatic life in estuaries and/or the Bay Delta estuary. They were published after or not referenced in the 2010 Flow Criteria Report.

2010

CAL. DEPT. OF FISH & GAME, QUANTIFIABLE BIOLOGICAL OBJECTIVES AND FLOW CRITERIA FOR AQUATIC AND TERRESTRIAL SPECIES OF CONCERN DEPENDENT ON THE DELTA (Nov. 23, 2010), available at http://www.dfg.ca.gov/water/water_rights_docs.html.

- Table 15: DFG Flow Criteria, pages 105-107, contains recommended flow criteria for aquatic life.
- Chapter 7, pages 32-93, contains useful information about aquatic habitat, flows, and life history traits of priority species including Chinook salmon, steelhead, longfin smelt, splittail, delta smelt, starry flounder, bay shrimp mysid shrimp, and American shad.

James A. Hobbs, JA, Lewis, L.S., Ikemiyagi N., Sommer, T, Baxter, R.T. (2010) The use of otolith strontium isotopes (87Sr/86Sr) to identify nursery habitat for a threatened estuarine fish. Environ Biol Fish (2010) 89:557–569 http://www.water.ca.gov/aes/docs/HobbsLongfin2010.pdf

- Low salinity habitats are important nursery areas for longfin smelt because they disproportionally contribute more longfin recruits (juveniles over a minimum size threshold) relative to both freshwater and brackish water habitats.
- The relative importance of the low salinity zone to successful recruitment appeared greatest in years following the longfin smelt population decline.

[1] Available at http://www.waterboards.ca.gov/waterrights/water_issues/programs/bay_delta/docs/pubnot_phs2wrkshps.pdf

Mac Nally R, Thomson JR, Kimmerer WJ, Feyrer F, Newman KB, Sih A, Bennett WA, Brown L, Fleishman E, Culberson SD, Castillo G. 2010. An analysis of pelagic species decline in the upper San Francisco Estuary using multivariate autoregressive modeling. Ecological Applications 20(5): 1417-1430.

- X2 and increased water clarity (reduced turbidity) were two factors affecting multiple declining fishes and their main zooplankton prey.
- Authors identify a strong relationship between Spring X2 and abundance of longfin smelt.
- Increases in water exports in both winter and spring were negatively associated with abundance of delta smelt and increases in spring exports with abundance of threadfin shad.

Nobriga, M.L. Bioenergetic modeling evidence for a context-dependent role of food limitation in California's Sacramento-San Joaquin Delta. California Fish and Game. Available at http://www.water.ca.gov/iep/docs/pod/NobrigaBioenergetic%20Modeling.pdf.

- Age-0 striped bass were less food limited than age-0 largemouth bass in recent years.
- Food limitation of age-0 striped bass occurs as a stressor interacting with other persistent stressors (e.g., high entrainment loss to water diversions) that all contribute to decreased habitat suitability.
- Rapid increases in habitat have facilitated largemouth bass population growth and are more important to largemouth bass' recent success than patterns of growth during the first year of life.

Thomson JR, Kimmerer WJ, Brown LR, Newman KB, Mac Nally R, Bennett WA, Feyrer F, Fleishman E. 2010. Bayesian change point analysis of abundance trends for pelagic fishes in the upper San Francisco Estuary. Ecological Applications 20(5): 1431-1448.

- Abiotic variables, including water clarity, X2, and the volume of freshwater exported from the estuary, explained some variation in species' abundances over the time series, but no selected covariates could explain statistically the post-2000 change points for any species.
- Species-specific, covariate-conditioned change point models show abrupt declines of delta smelt and longfin smelt in 2004 and of striped bass and threadfin shad in 2002.
- Water clarity and winter exports both had high probability of inclusion and a negative effect on delta smelt; water clarity and spring X2 had high probability of inclusion for longfin smelt.

York J, Costas B, McManus G. 2010. Microzooplankton grazing in green water—results from two contrasting estuaries. Estuaries and Coasts 34: 373-385.

- The authors found many instances of saturated and insignificant grazing of phytoplankton by microzooplankton in San Francisco Bay.
- Saturation in some cases may result from high particle loads.
- Insignificant grazing may result from extreme saturation of the grazing response due to the need to process non-food particles.
- There was no evidence of nutrient limitation for phytoplankton growth.
- The authors found increasing phytoplankton growth rates and microzooplankton grazing rates with increasing salinity in the spring and summer of 2007.

- Grazing rates in San Francisco Bay and Long Island Sound were similar to those found in other estuaries.

2011

Frederick Feyrer et al., Modeling the Effects of Future Outflow on the Abiotic Habitat of an Imperiled Estuarine Fish, ESTUARIES & COASTS (2011) 34: 120-128, available at http://www.springerlink.com/content/d22u618x244n7j46/fulltext.pdf.

- The quantity and quality of the delta smelt habitat index (salinity and turbidity) decreased by 78% between 1967 and 2008. A key part of the concern for delta smelt is that the lowest levels of suitable habitat coincide with the habitat being located further upstream in closer proximity to anthropogenic sources of mortality such as water diversions and certain contaminant sources.
- Locations of LSZ downstream of the confluence of the Sacramento and San Joaquin rivers results in a dramatic increase in the habitat index, when the LSZ encompasses the expansive Suisun and Grizzly Bays, a larger area of suitable habitat.
- Food density, entrainment risk, predation risk, and exposure to contaminants are habitat elements affected by salinity and turbidity which must be present for smelt to use the habitat.
- Increased habitat area is likely to reduce any density-dependent effects on the delta smelt population.
- Delta smelt will face serious threats if water demand increases and climate change projections are realized.

Maunder, M.N, and R.B. Deriso. 2011. A state–space multistage life cycle model to evaluate population impacts in the presence of density dependence: illustrated with application to delta smelt (Hyposmesus transpacificus). Canadian Journal of Fisheries and Aquatic Sciences 68:1285–1306.

- An annual multistage life cycle model was created in which the number of individuals in the first life stage (e.g., delta smelt larvae) is determined by the number of individuals in the last stage of the previous year (delta smelt adults that reproduced).
- The state-space model is used to numerically describe the transition from one life stage to the next.
- Several factors thought to impact abundance were evaluated including entrainment, food abundance, temperature, predator abundance, and turbidity. Although exports were identified as an important factor, they were assumed to be related to entrainment.
- Results indicate that, of the parameters included, food abundance, temperature, predator abundance, and density dependence are most important in controlling the population dynamics of delta smelt.

Schoellhamer DH. 2011. Sudden clearing of estuarine waters upon crossing the threshold from transport to supply regulation of sediment transport as an erodible sediment pool is depleted: San Francisco Bay, 1999. Estuaries and Coasts 34: 885-899

- Changes in the San Francisco Bay ecosystem in the 2000s have been symptomatic of sudden sediment clearing.

- A statistically significant 36% step decrease in SSC in San Francisco Bay from water years 1991–1998 to 1999–2007.
- Depletion of an erodible sediment pool in 1999 would cause a sudden decrease in SSC.
- Supply of hydraulic mining sediment increased bed sediment volume by at least 260 Mm^3 in the late 1800s, almost entirely in Suisun and San Pablo Bay.

Winder M, Jassby AD. 2011. Shifts in zooplankton community structure: implications for food web processes in the upper San Francisco Estuary. Estuaries and Coasts 34: 675-690.

- Increased water diversion at times of decreased water availability exacerbated the effects of post-1960 droughts by further reducing freshwater inflow.
- Amplifying outflow reductions during a drought increased drought severity and allowed unusually extreme salinity intrusions and invertebrate invasions.
- These conditions intensified benthic grazing on native invertebrates allowing invasive invertebrates to colonize.

2012

EPA convened a Technical Workshop on Estuarine Habitat in the Bay Delta Estuary on March 27, 2012 ("2012 EPA Workshop") to discuss and advance understanding in the scientific community about the relationship between the low salinity zone, salinity gradient, and the abundance of fish species. EPA worked with Aquatic Science Center and other partners to produce a number of resources relevant to the Board's review of the Bay-Delta Plan.

- San Francisco Bay Delta Estuarine Habitat Workshop Agenda (PDF) (5 pp, 319K)
- Review of San Francisco Bay Delta Estuary Low Salinity Zone Scientific Papers and Summary of Key Findings (PDF) (30 pp, 424K)
- Description of Estuarine Habitat, Low Salinity Zone, and X2 Models (PDF) (14 pp, 836K)
- Notes on Estimating X2 with DAYFLOW (PDF) (5 pp, 405K)
- Data for Notes on Estimating X2 with DAYFLOW (.XLSX) (738K)
- Salinity and flow in Northern San Francisco Bay: Physics and Modeling (SUNTANS) (PDF) (12 pp, 993K) -- Stephen Monismith
- Modeling Estuarine Habitat using the UnTRIM Bay-Delta Model (PDF) (28 pp, 1.22M) -- Michael MacWilliams
- Historical Perspectives on the Estuarine Gradient (PDF) (27 pp, 4.71M) -- Robin Grossinger
- Low Salinity Zone Workshop Summary (PDF) (69 pp, 1.57 MB)

Workshop materials are available at the hyperlinks provided in the above list and at the EPA SF Bay Delta website www.epa.gov/sfbaydelta/activities. Scroll down and click on Sacramento-San Joaquin Delta Water Quality Standards to reveal the collapsed list identical to the one above.

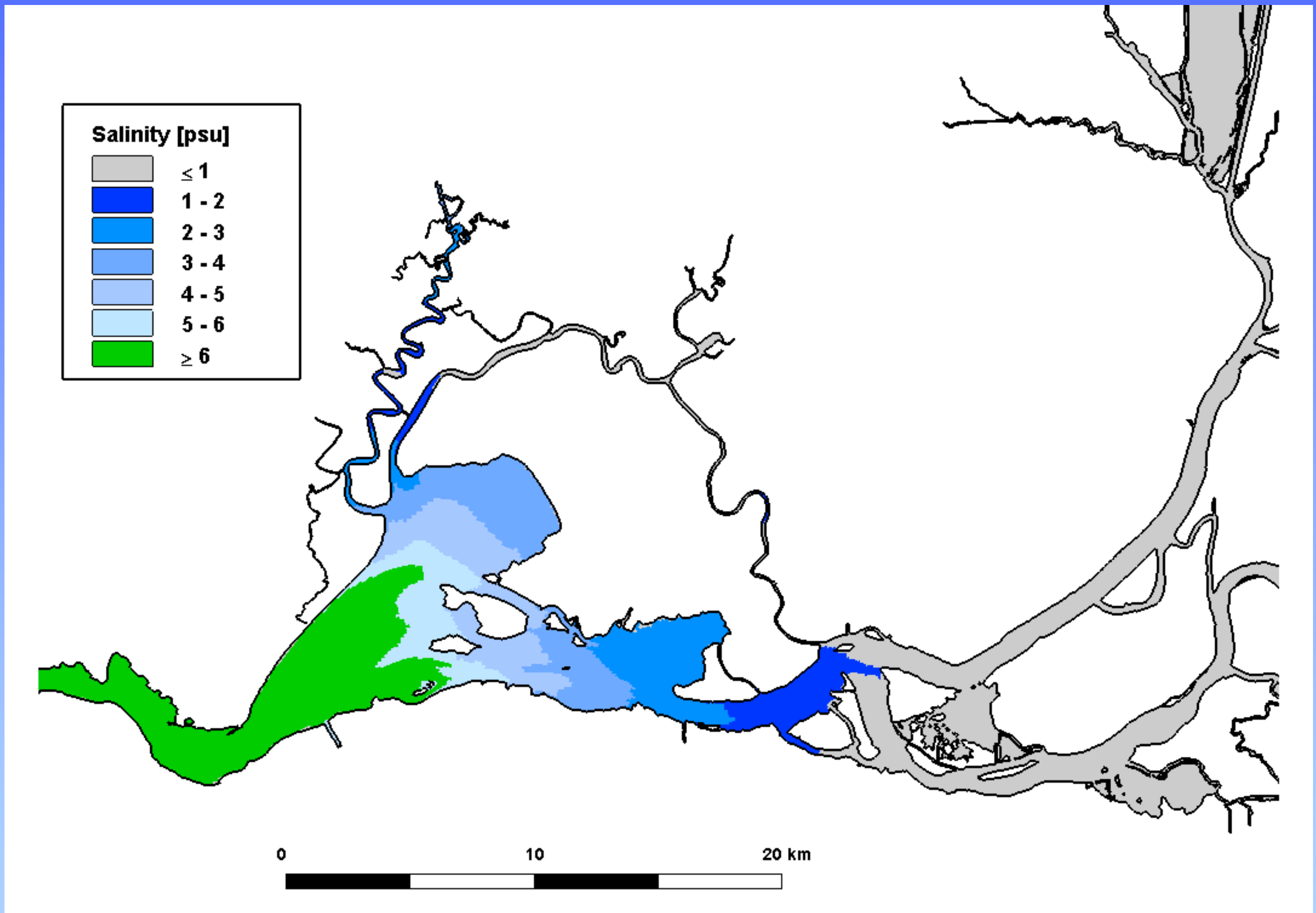
Miller, W.J., B.F.J. Manly, D.D. Murphy, D. Fullerton, and R.R. Ramey. 2012. An investigation of factors affecting the decline of delta smelt (Hypomesus transpacificus) in the Sacramento-San Joaquin Estuary. Reviews in Fisheries Science 20:1-19.

- Authors used the Ricker population abundance model and initial quantification of factors they determined to have a direct impact on delta smelt abundance (Figure 2, page 5).
- Identifies prey density as the most important environmental factor explaining variations in delta smelt abundance from 1972 to 2006 and over the recent period of decline.
- Delta smelt entrainment at south Delta pumping plants had an impact on adult-to-juvenile survival but not over the fish's life cycle.
- Fall X2 did not explain delta smelt population trends beyond those accounted for by prey density.

NRC (National Research Council). 2012. Sustainable water and environmental management in the California Bay-Delta. National Research Council. The National Academies Press, Washington, DC.

- A thorough discussion regarding the development and use of X2 as an indicator of estuarine organism abundance and as a regulatory tool to protect aquatic life (see pages 53 – 60).
- Mechanisms explaining the impact of X2 on abundance of a variety of biota remain hypothetical.
- However, statistical relations reported in several papers show that abundance of a number of species at different trophic levels found in the Delta and San Francisco Bay is higher when X2 is lower (farther downstream).
- This implies that reductions in outflow would tend to reduce the abundance of these organisms.

Low Salinity Zone Flip Book



DELTA MODELING ASSOCIATES

Version 0.9

June 15, 2012

About

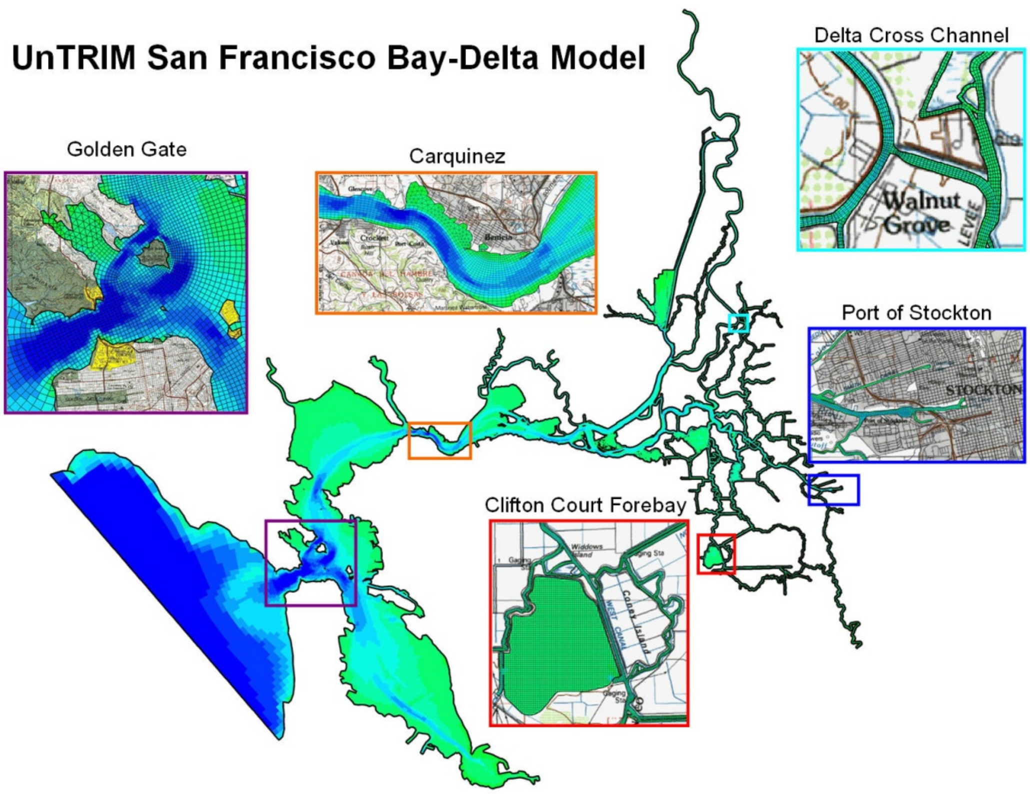
- The Low Salinity Zone (LSZ) Flip Book developed out of a collaboration between Michael MacWilliams (Delta Modeling Associates, Inc.) and Bruce Herbold (US EPA) with input from Larry Brown (USGS).
- The goal of this document is to encourage discussion of ways of thinking about X2 and the LSZ both spatially and temporally.
- Comments and suggestions for ways to improve the usefulness of this document are welcome. Please email comments to: michael@deltamodeling.com

Overview

- In this analysis the Low Salinity Zone (LSZ) is defined as the region where the daily-averaged depth-averaged salinity is between 1 and 6 psu.
- The 3-D UnTRIM San Francisco Bay-Delta Model (MacWilliams et al., 2008; MacWilliams et al., 2009) was applied to simulate an eighteen-month period between April 1994 and September 1995.
- The model validation for the salinity predictions during this period will be documented in an upcoming paper in collaboration with Wim Kimmerer and Edward Gross.

UnTRIM Bay-Delta Model

- The UnTRIM Bay-Delta model is a three-dimensional hydrodynamic model of San Francisco Bay and the Sacramento-San Joaquin Delta.



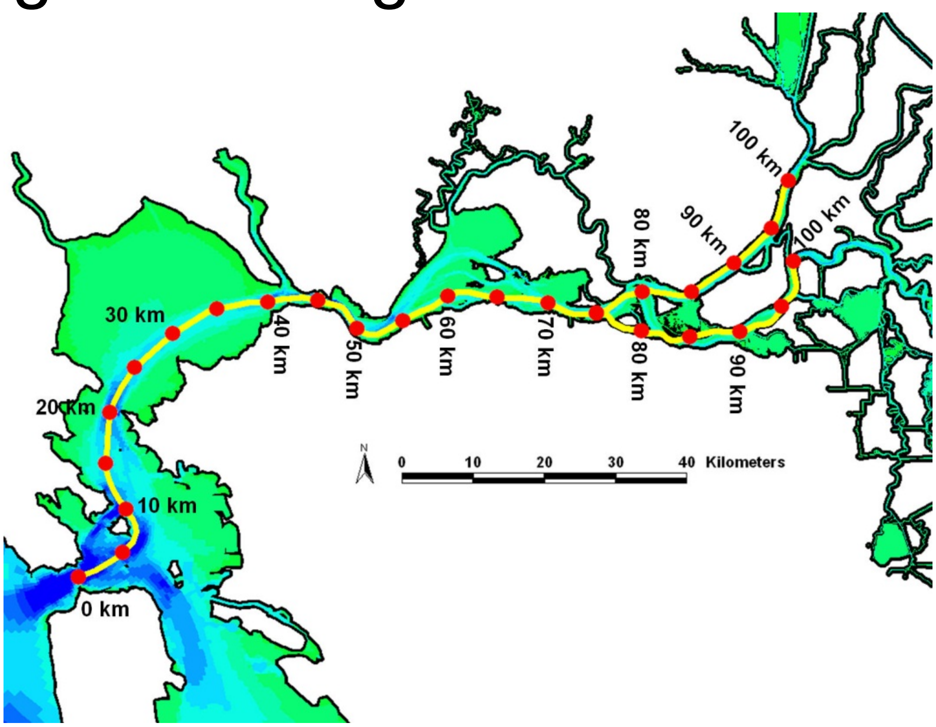
- Additional information about the UnTRIM Bay-Delta Model can be found at: http://www.deltamodeling.com/untrimbaydeltamodel.html

LSZ Modeling Approach

- For each model time step (90 seconds) the depth-averaged salinity is calculated within each mode grid cell in the model domain. The daily-averaged depth-averaged salinity is calculated as the average of the depth-averaged salinity at each of 960 modeled time steps in each day.
- The daily-averaged LSZ area for each day is calculated as the summation of all grid cells with daily-averaged depth-averaged salinity between 1 and 6 psu.
- The time that the LSZ is within each grid cell is calculated from the depth-averaged salinity saved hourly for each day to allow for visualization of LSZ tidal excursion.

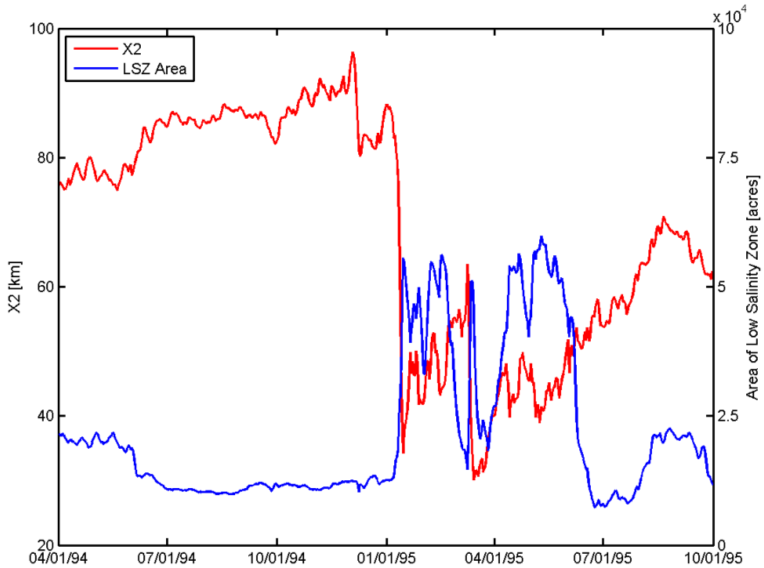
X2 Modeling Approach

- X2 is defined as the position of the 2 psu bottom salinity value, measured along the axis of the estuary in km from the Golden Gate.
- X2 is calculated on each day from the model simulations using the daily-averaged near-bed salinity along the transects shown below. When X2 is greater than 74, X2 is calculated as the average X2 along the two transects.

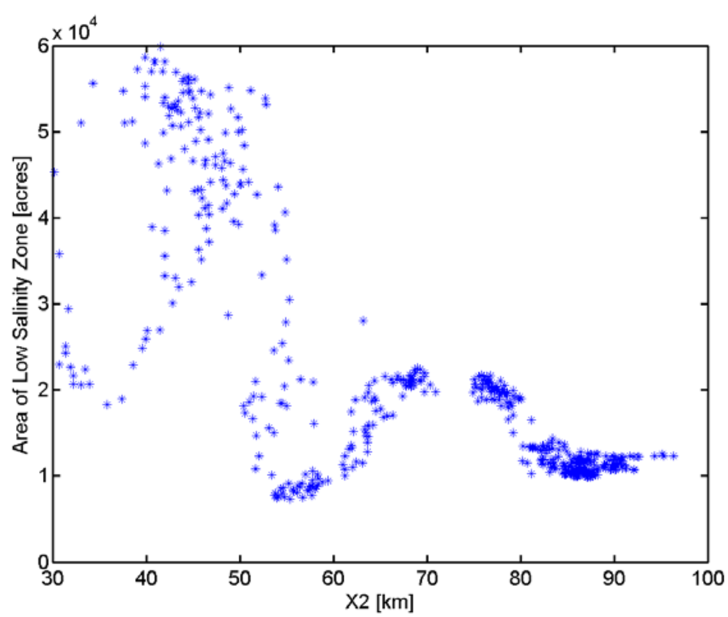


Relationship Between LSZ and X2

- The top figure shows X2 and the LSZ area calculated for each day during the 18-month simulation.



- The bottom figure shows the LSZ area plotted as a function of X2 using values calculated on 548 days.



How to use the LSZ Flip Book

- The LSZ Flip Book is designed to provide an easy way to visualize both the average position of the LSZ and the tidal excursion of the LSZ over a range of X2.
- From the eighteen-month simulation period, individual days were selected to show the position and tidal excursion of the LSZ for a range of conditions with X2 between 55 and 95 km.
- Conditions shown for a given X2 are specific to a single day. To the extent possible the days are selected to provide representative conditions for a given X2.
- Not all X2 values are shown in part because some X2 values did not exactly occur within the period simulated.

How not to use the LSZ Flip Book

- The LSZ Flip Book is not designed to give an exact representation of the LSZ position for a specified X2.
- The model has been validated using available salinity data, however limited data are available for calibration outside of the channel and in Suisun Marsh.
- The calculated X2 on a each day is typically within 0.1 km of the value reported on the top of each page.
- The position of the LSZ can vary significantly for a given X2 depending on antecedent conditions (see page 31).
- The tidal excursion of the LSZ changes over the spring-neap cycle.
- Thus, the LSZ maps serve as a general guide given the above caveats.

LSZ Flip Book Layout

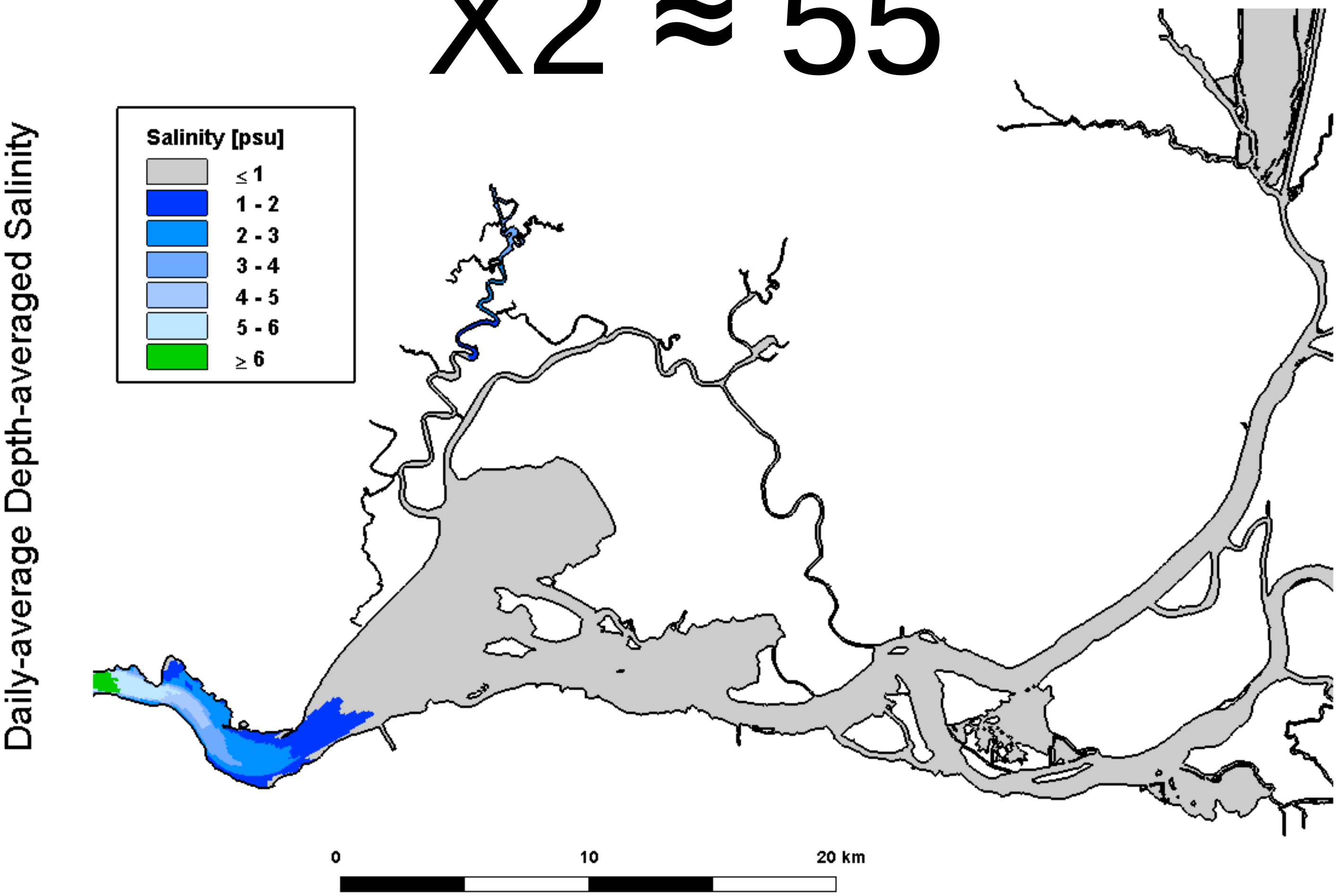
(Pages 10-29)

- Title: The approximate X2 calculated from the near-bed salinity for the day plotted below.

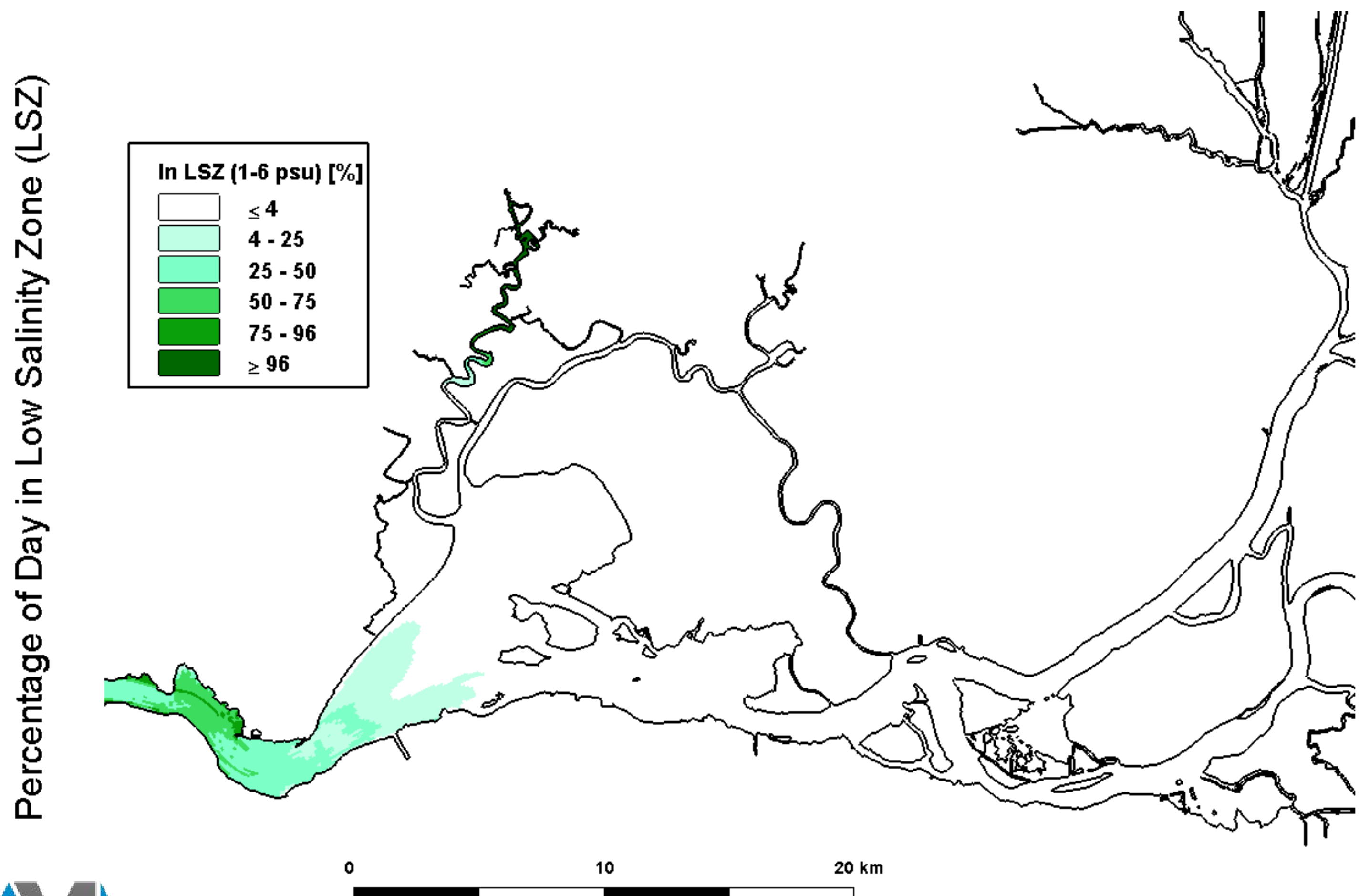
- Top Panel: This figure shows the daily-averaged depth-average salinity between Carquinez Strait and the Western Delta for a specific day from the 1994-1995 simulation during which the predicted X2 is similar to the target value shown at the top of the figure. Due to the influence of antecedent conditions, this day may not necessarily be representative of all days with a similar X2.

- Bottom Panel: For the day shown in the top panel, this figure shows the percentage of the day that salinity is between 1 psu and 6 psu based on twenty-four hourly depth-average salinity calculations. Tidal excursion varies significantly over the spring-neap cycle so this may not be representative for all days with a similar X2.

X2 ≈ 55



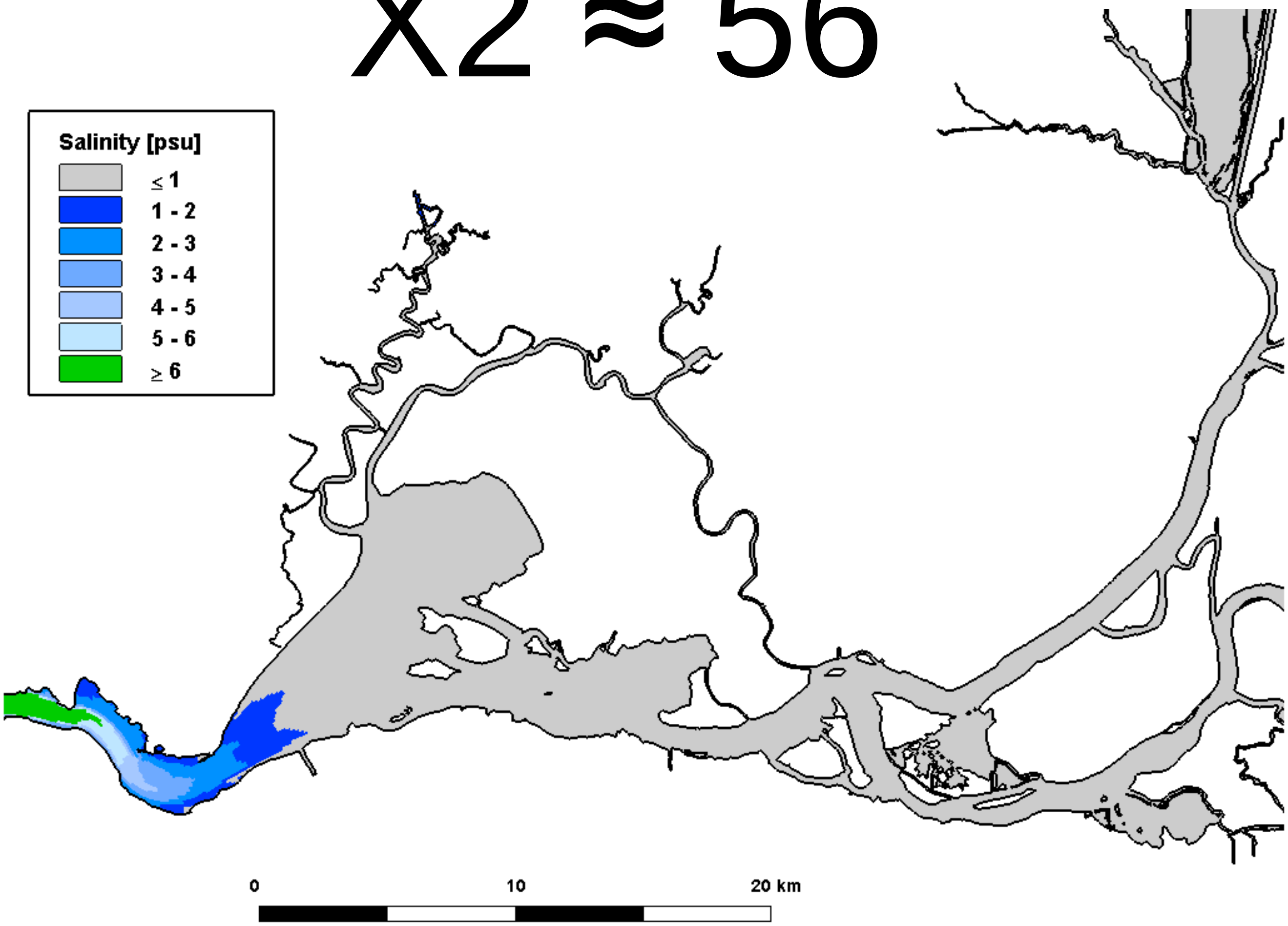
Daily-average Depth-averaged Salinity
Salinity [psu]
≤ 1
1 - 2
2 - 3
3 - 4
4 - 5
5 - 6
≥ 6
0
10
20 km



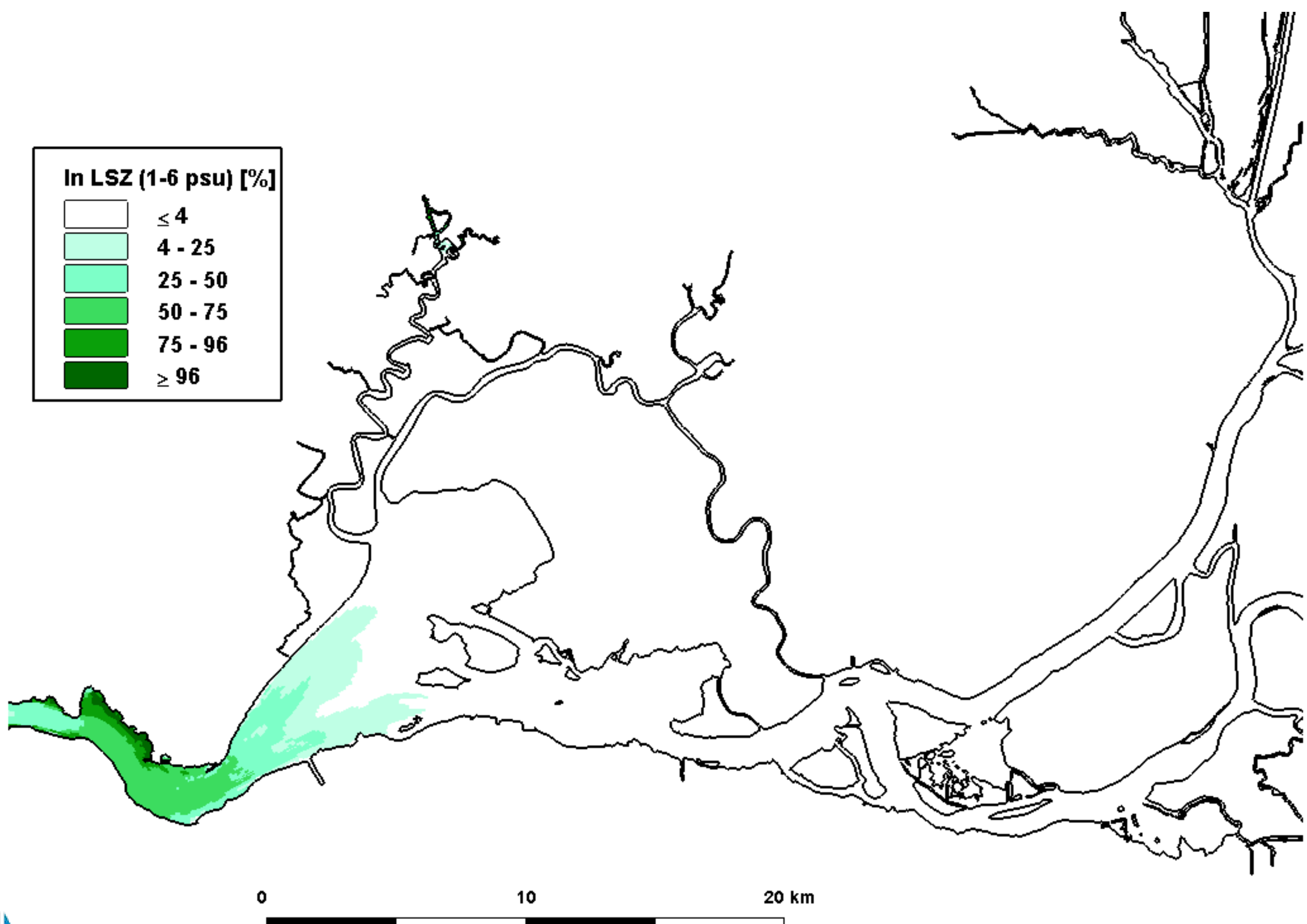
Percentage of Day in Low Salinity Zone (LSZ)
In LSZ (1-6 psu) [%]
≤ 4
4 - 25
25 - 50
50 - 75
75 - 96
≥ 96
0
10
20 km

X2 ≈ 56

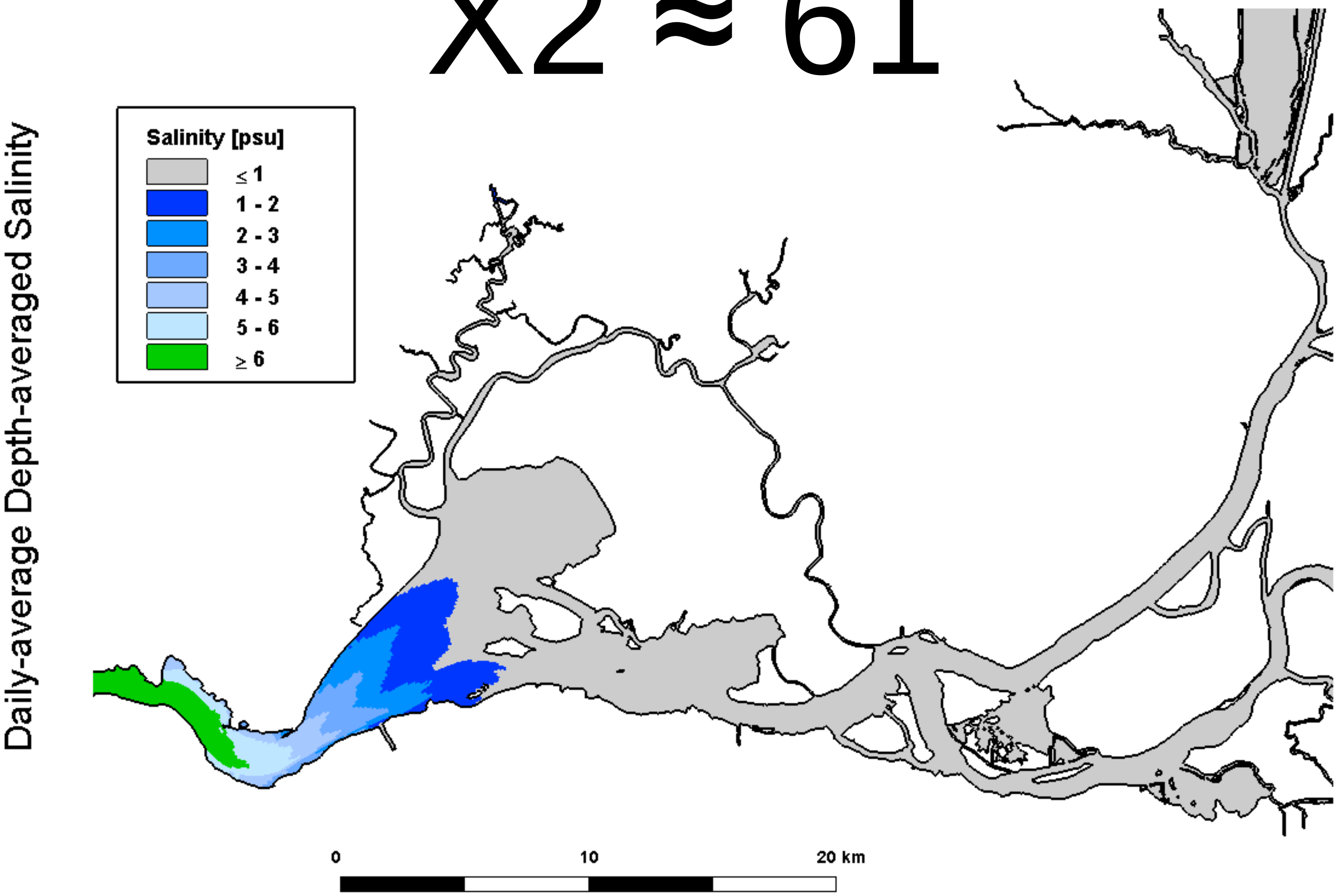
Daily-average Depth-averaged Salinity

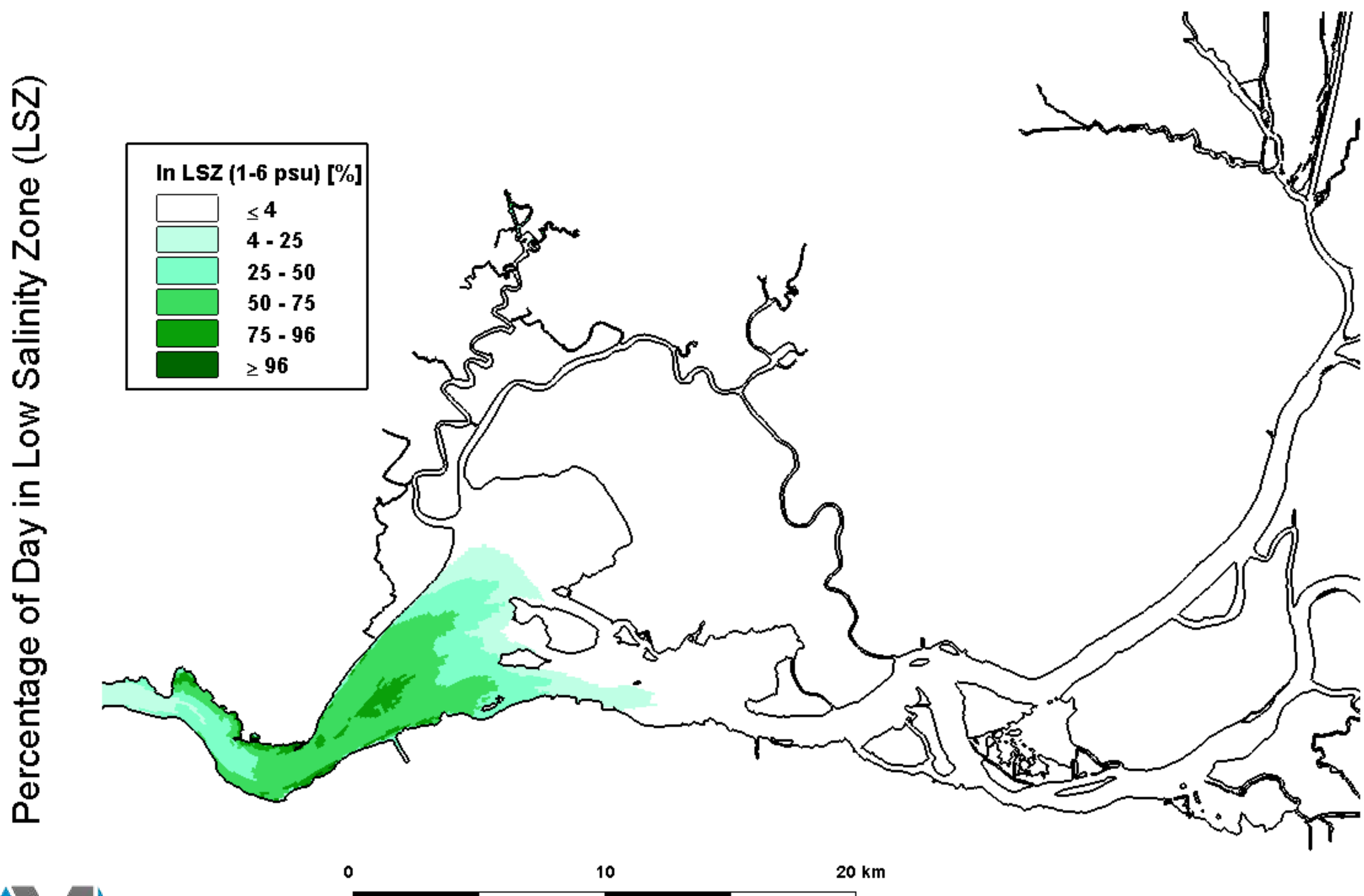


Percentage of Day in Low Salinity Zone (LSZ)



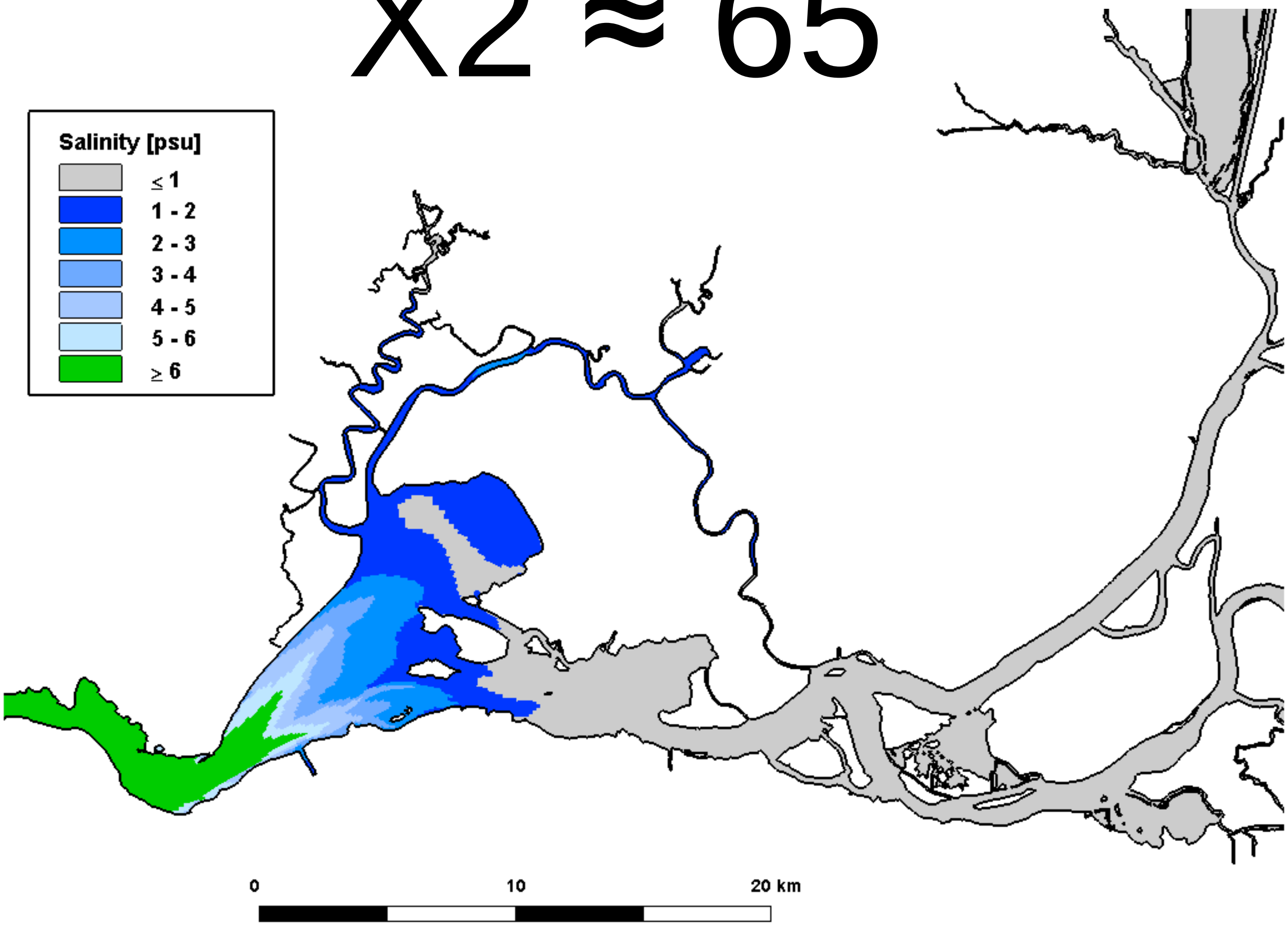
X2 ≈ 61


Daily-average Depth-averaged Salinity
Salinity [psu]
≤ 1
1 - 2
2 - 3
3 - 4
4 - 5
5 - 6
≥ 6
0
10
20 km

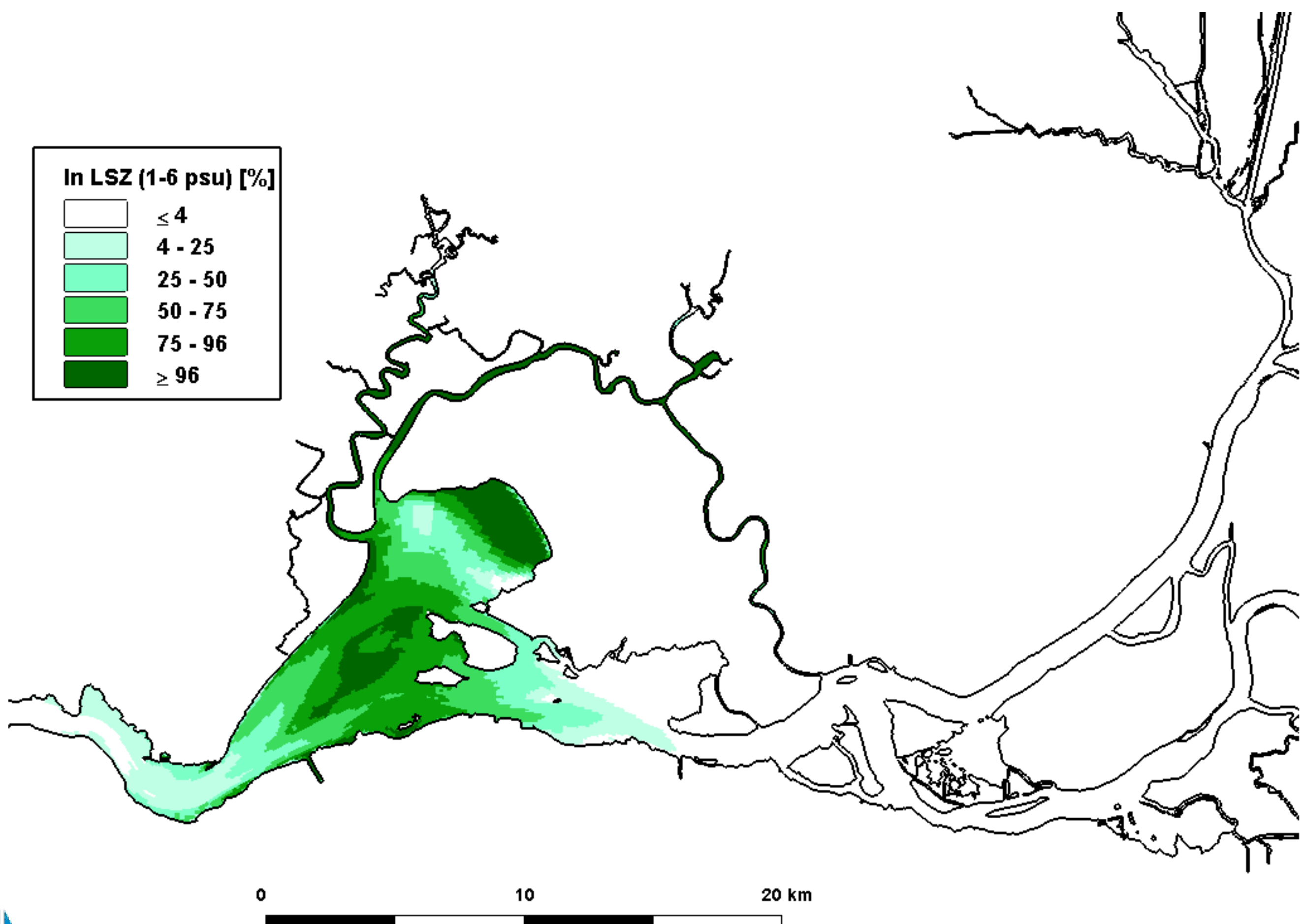

Percentage of Day in Low Salinity Zone (LSZ)
In LSZ (1-6 psu) [%]
≤ 4
4 - 25
25 - 50
50 - 75
75 - 96
≥ 96
0
10
20 km

X2 ≈ 65

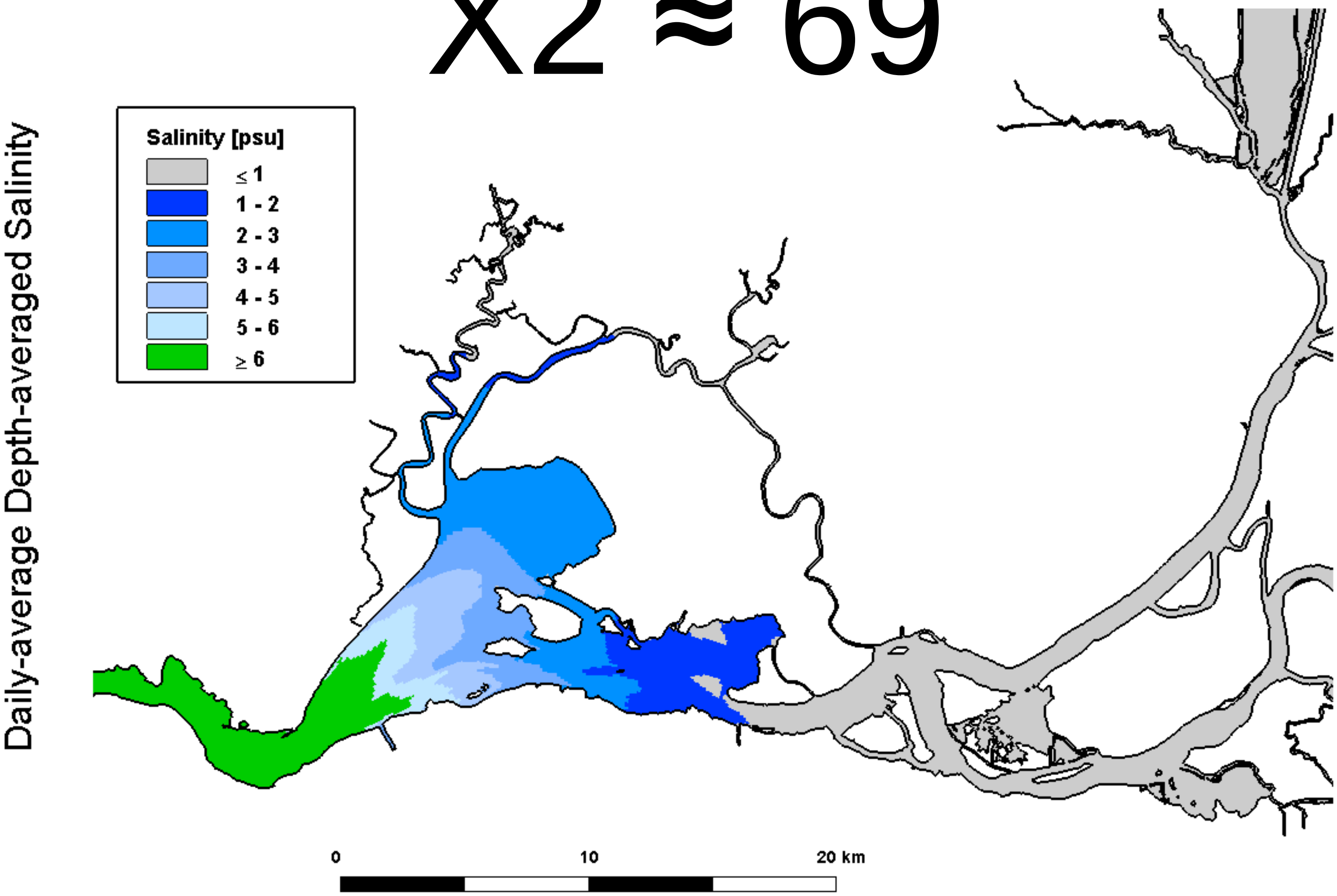
Daily-average Depth-averaged Salinity

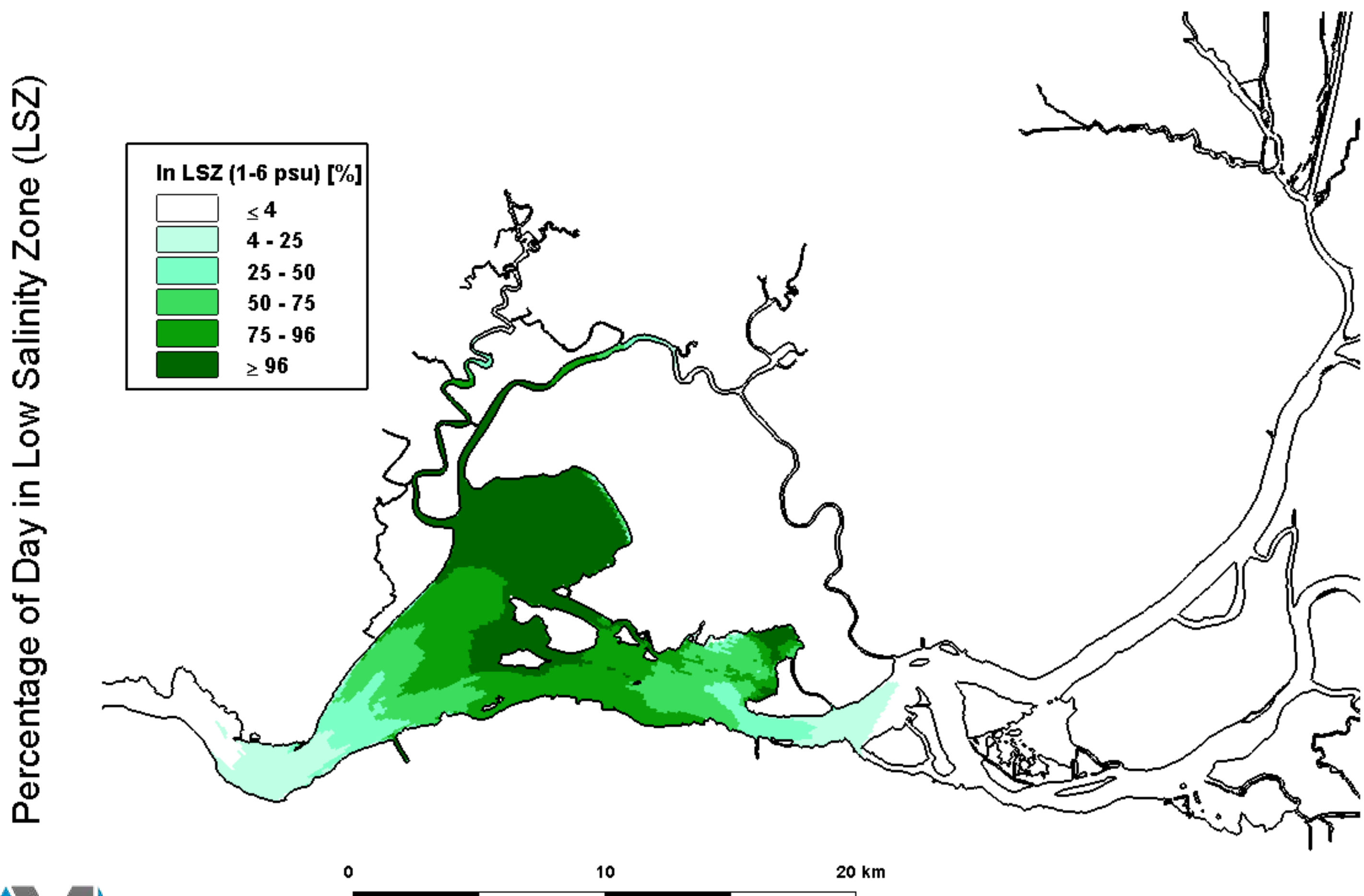


Percentage of Day in Low Salinity Zone (LSZ)



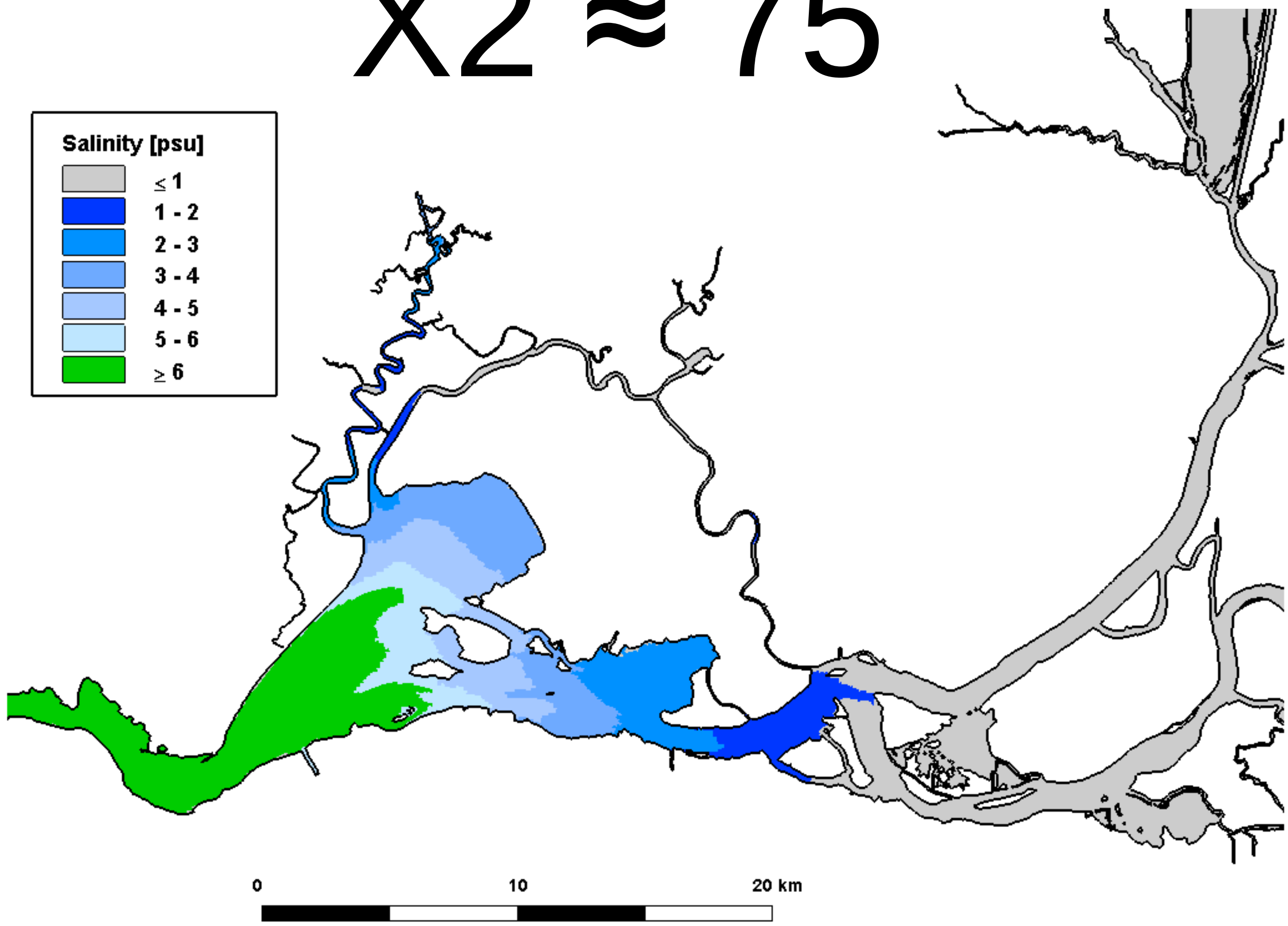
X2 ≈ 69


Daily-average Depth-averaged Salinity
Salinity [psu]
≤ 1
1 - 2
2 - 3
3 - 4
4 - 5
5 - 6
≥ 6
0
10
20 km

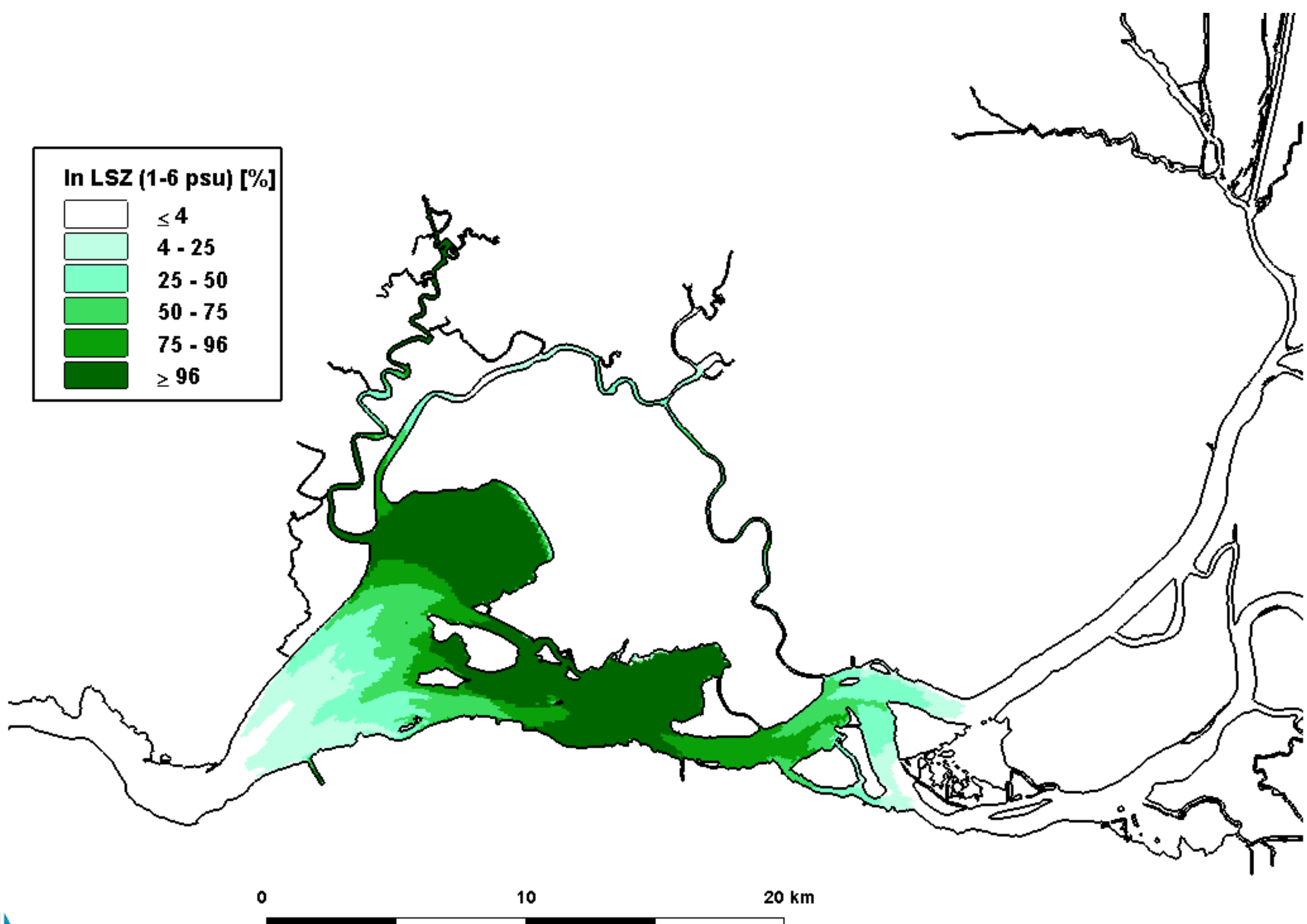

Percentage of Day in Low Salinity Zone (LSZ)
In LSZ (1-6 psu) [%]
≤ 4
4 - 25
25 - 50
50 - 75
75 - 96
≥ 96
0
10
20 km

X2 ≈ 75

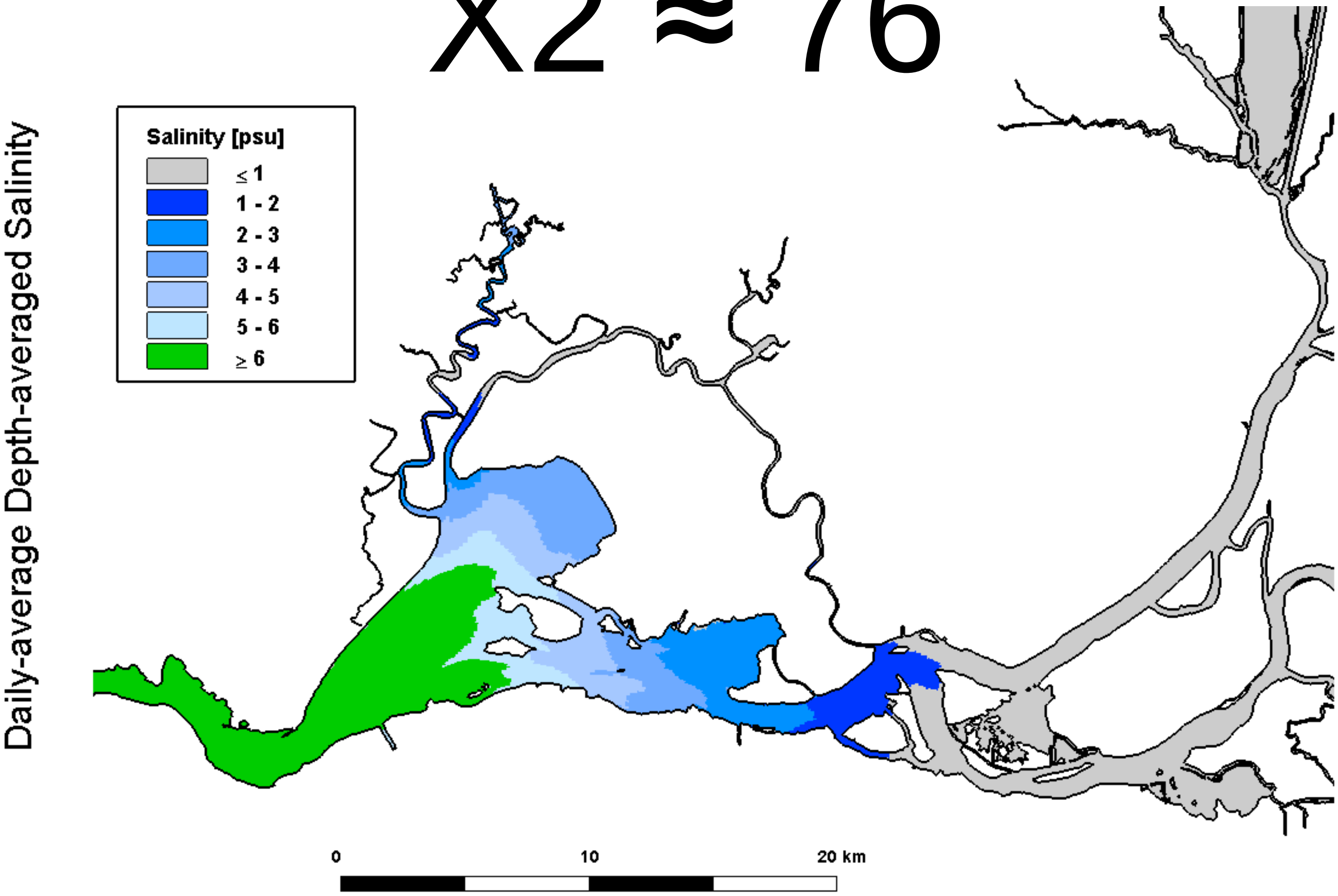
Daily-average Depth-averaged Salinity

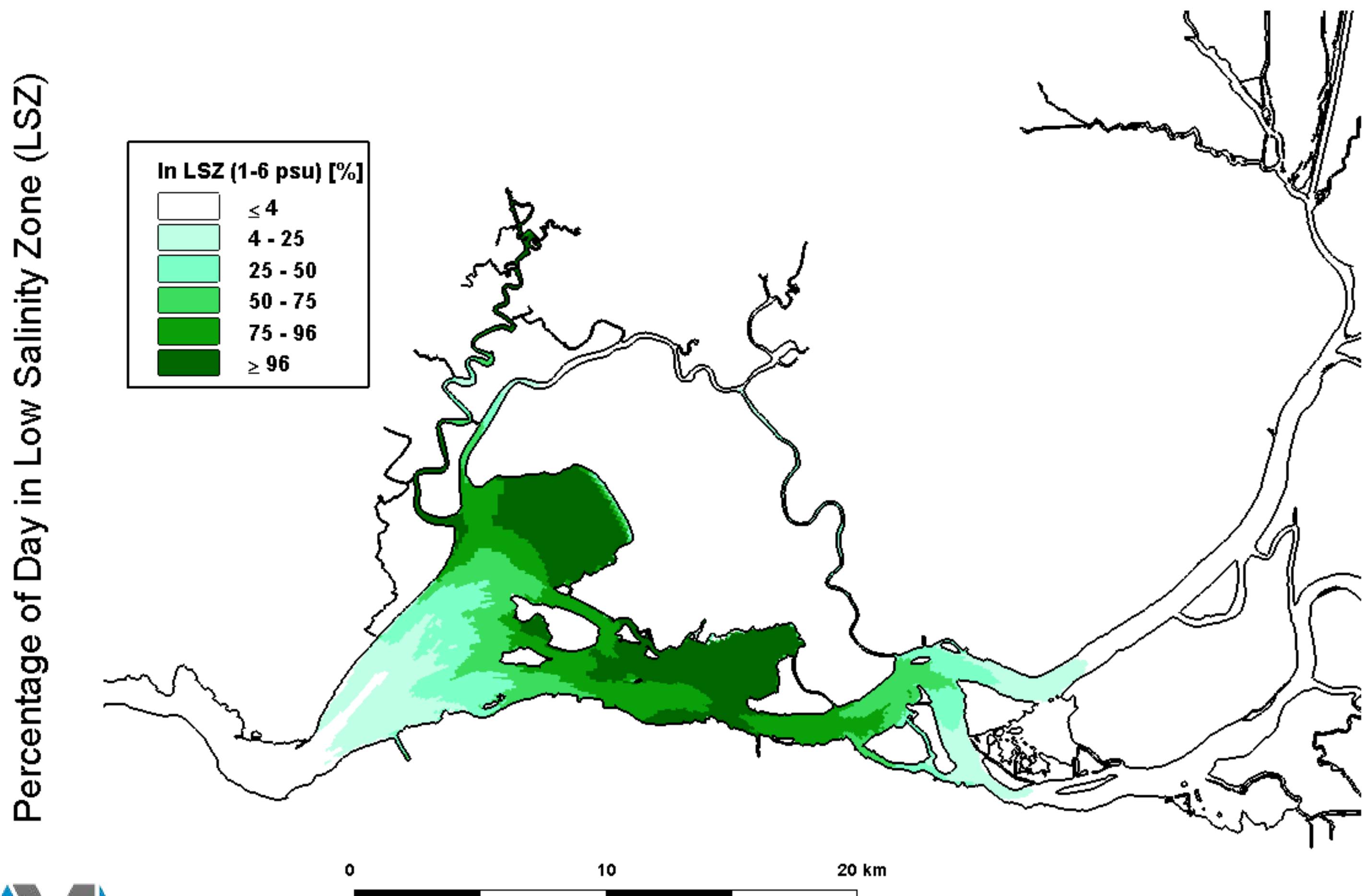


Percentage of Day in Low Salinity Zone (LSZ)

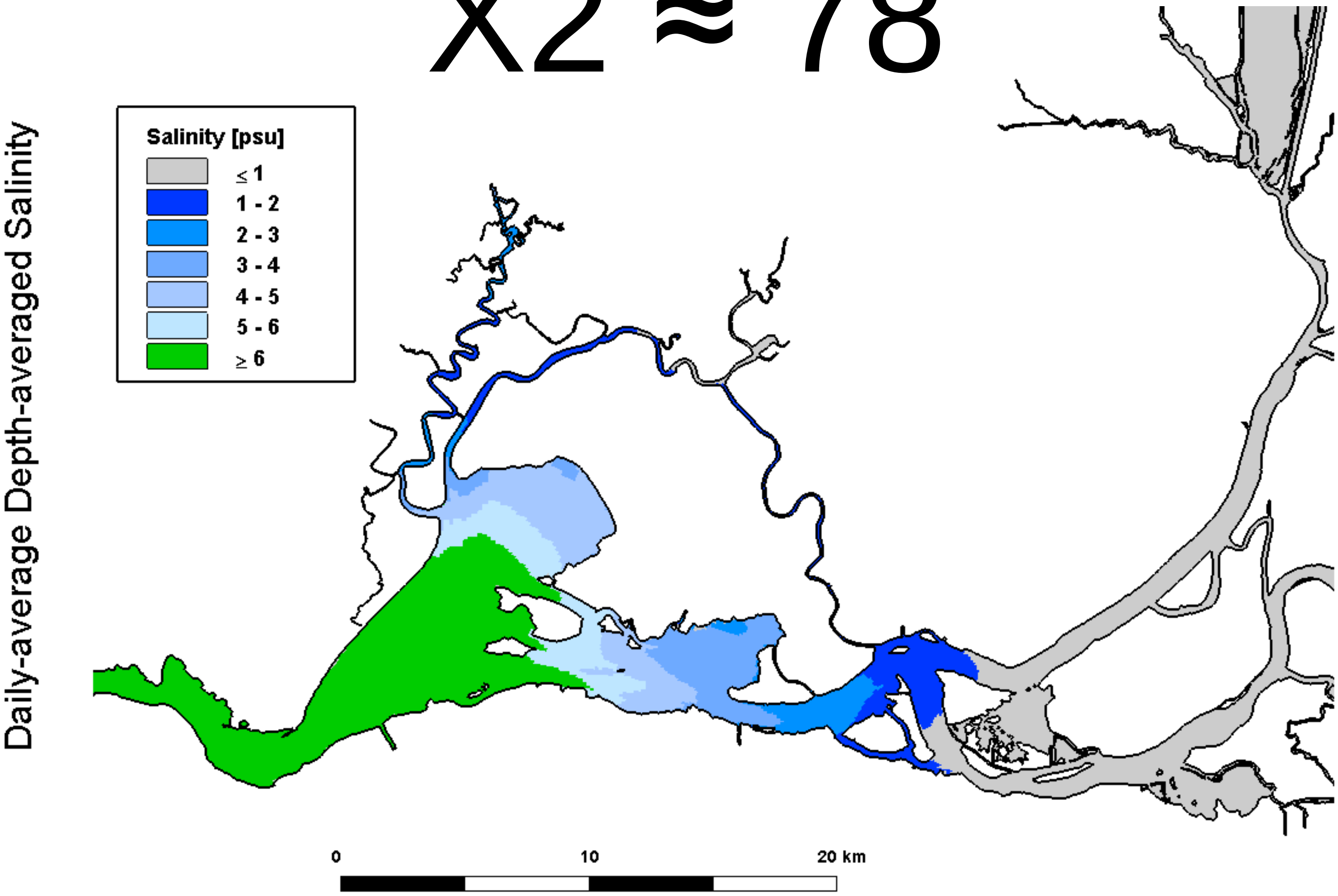


X2 ≈ 76

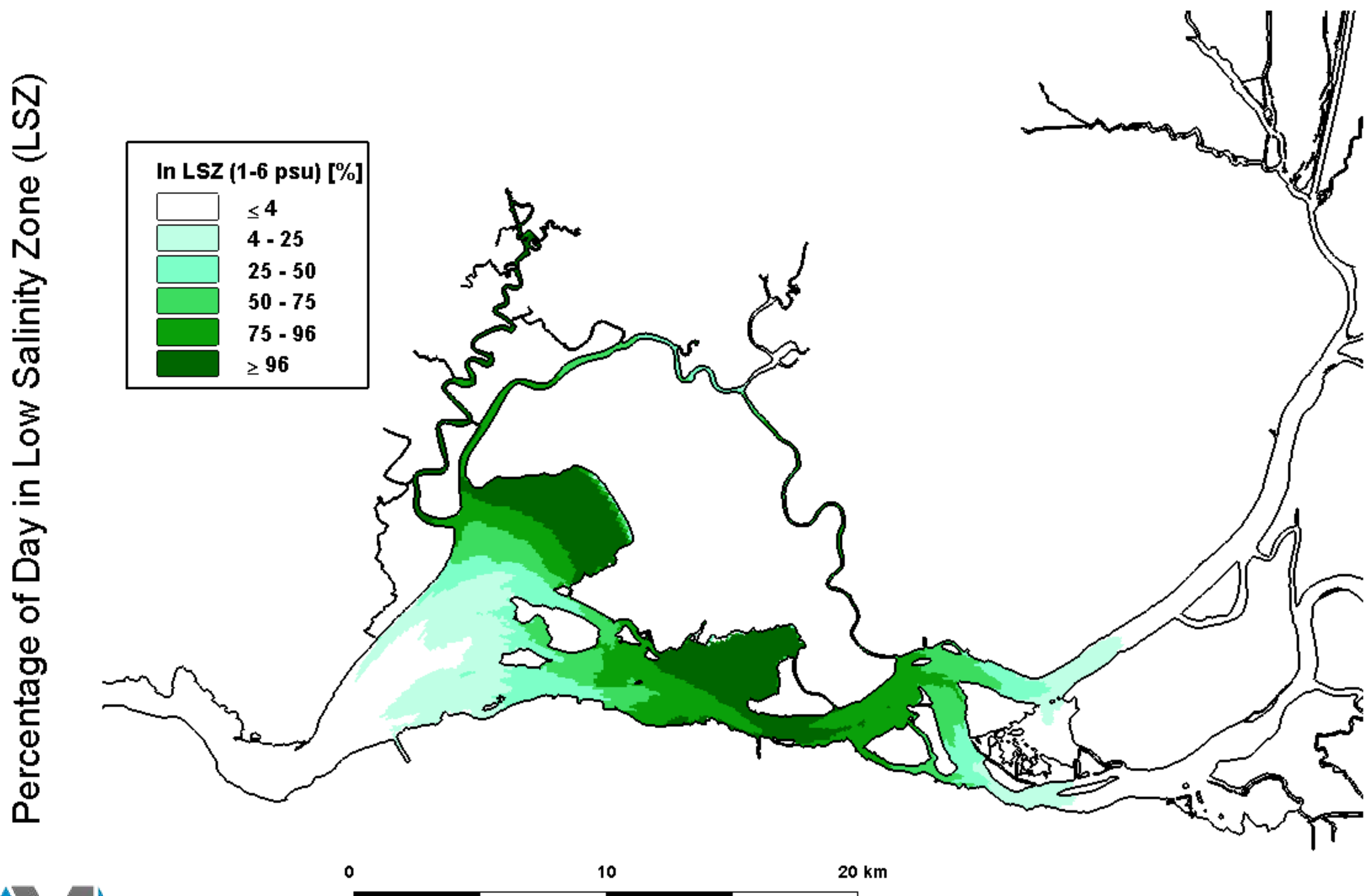

Daily-average Depth-averaged Salinity
Salinity [psu]
≤ 1
1 - 2
2 - 3
3 - 4
4 - 5
5 - 6
≥ 6
0
10
20 km


Percentage of Day in Low Salinity Zone (LSZ)
In LSZ (1-6 psu) [%]
≤ 4
4 - 25
25 - 50
50 - 75
75 - 96
≥ 96
0
10
20 km

X2 ≈ 78

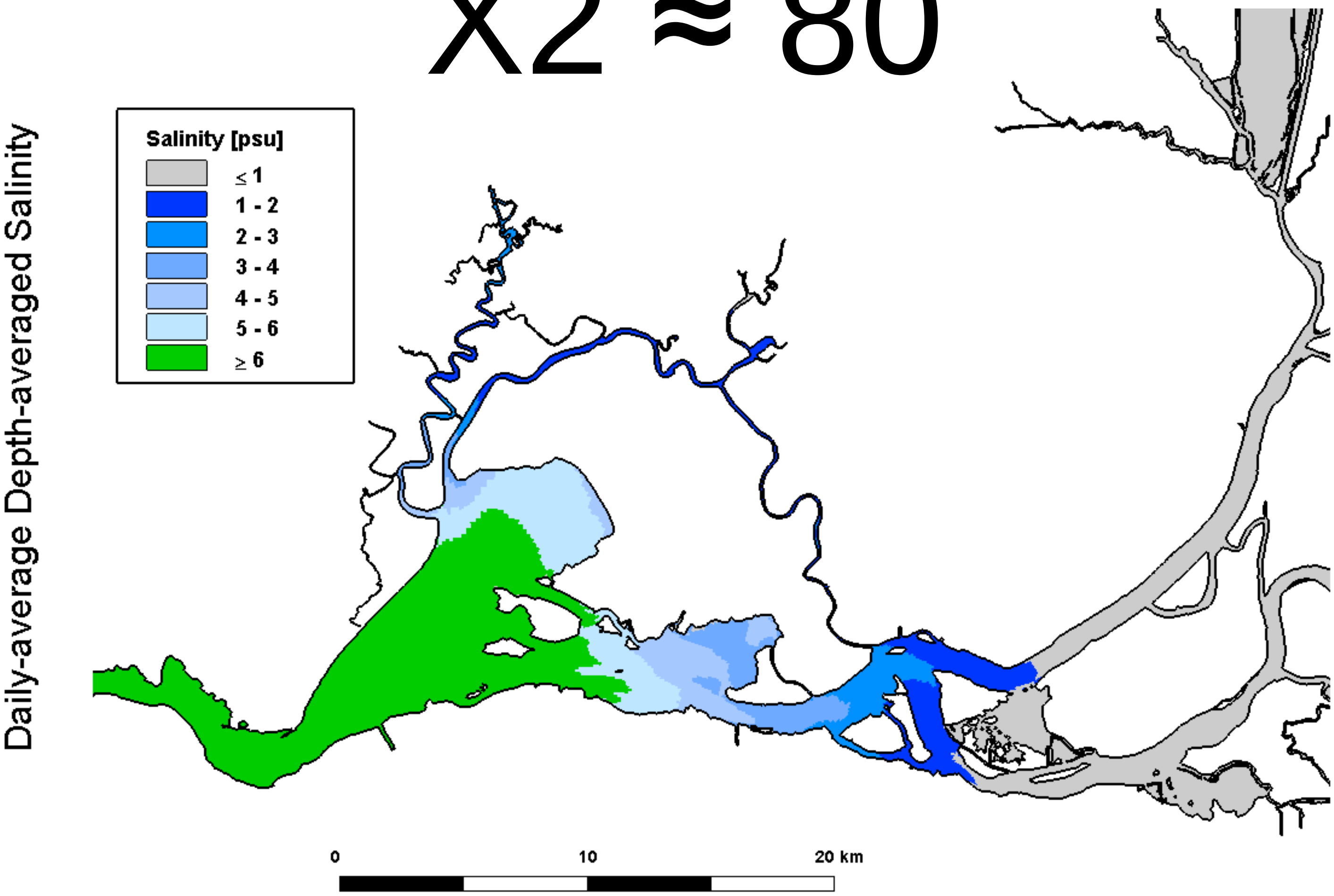


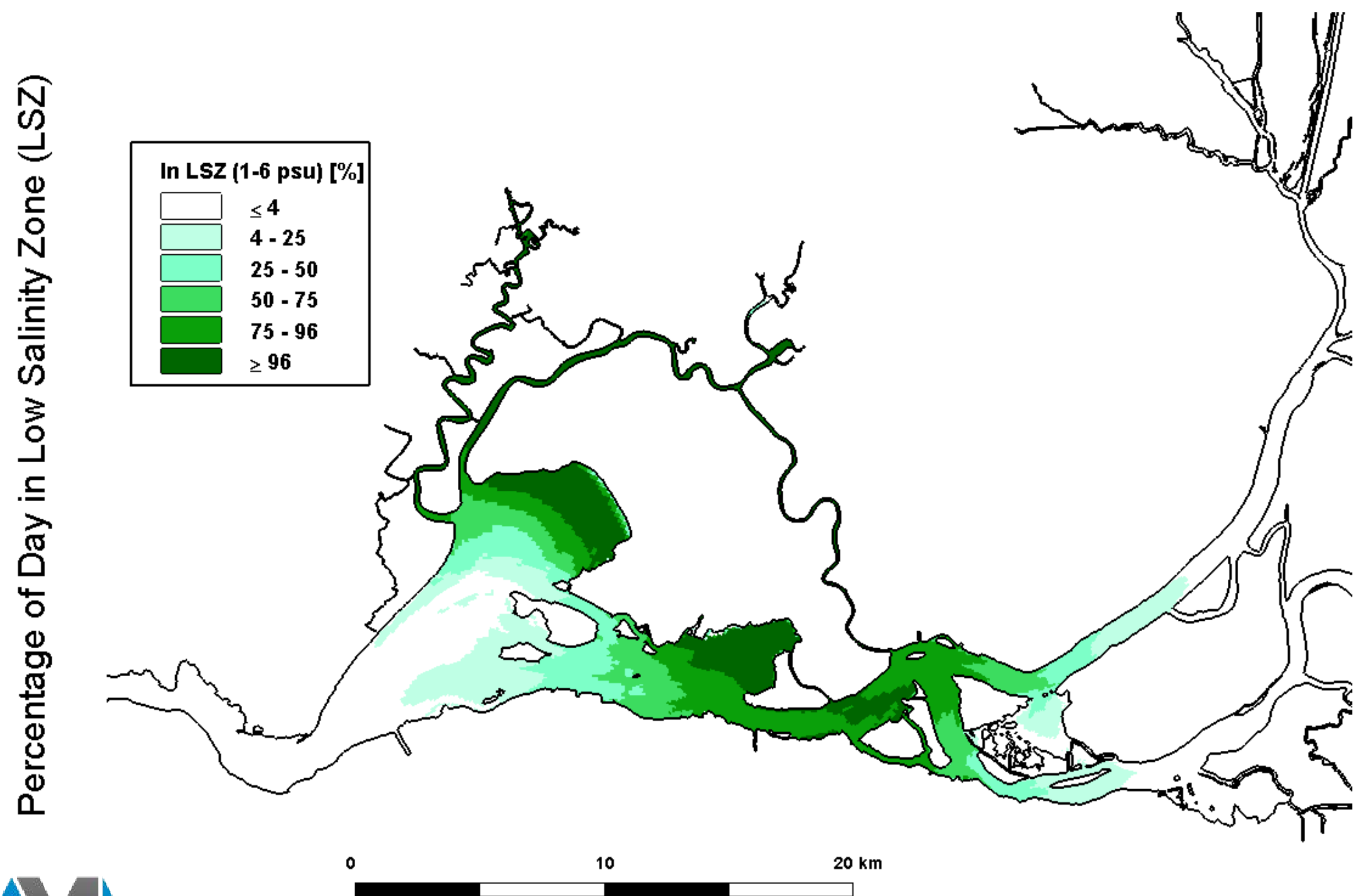
Daily-average Depth-averaged Salinity
Salinity [psu]
≤ 1
1 - 2
2 - 3
3 - 4
4 - 5
5 - 6
≥ 6
0
10
20 km



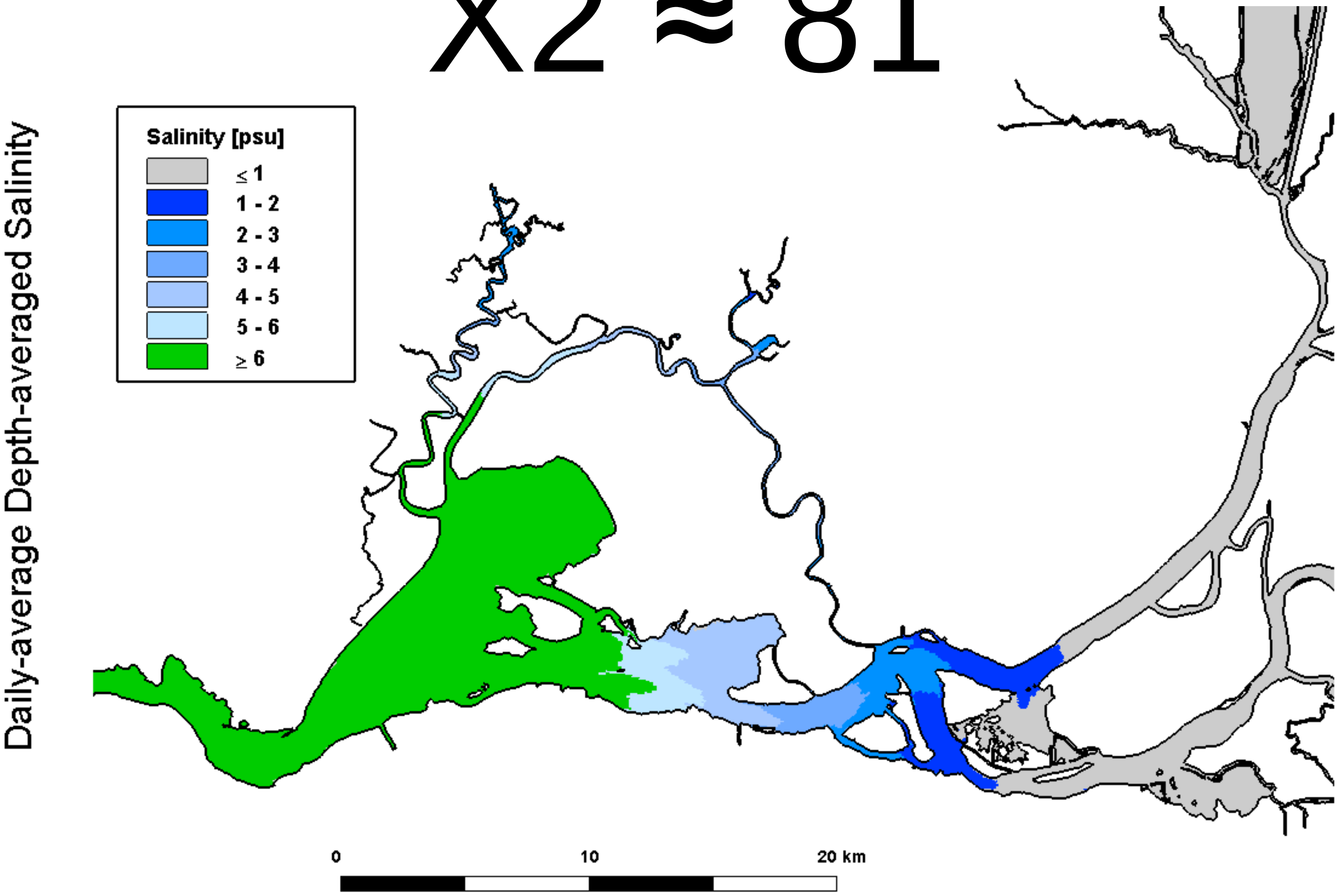
Percentage of Day in Low Salinity Zone (LSZ)
In LSZ (1-6 psu) [%]
≤ 4
4 - 25
25 - 50
50 - 75
75 - 96
≥ 96
0
10
20 km

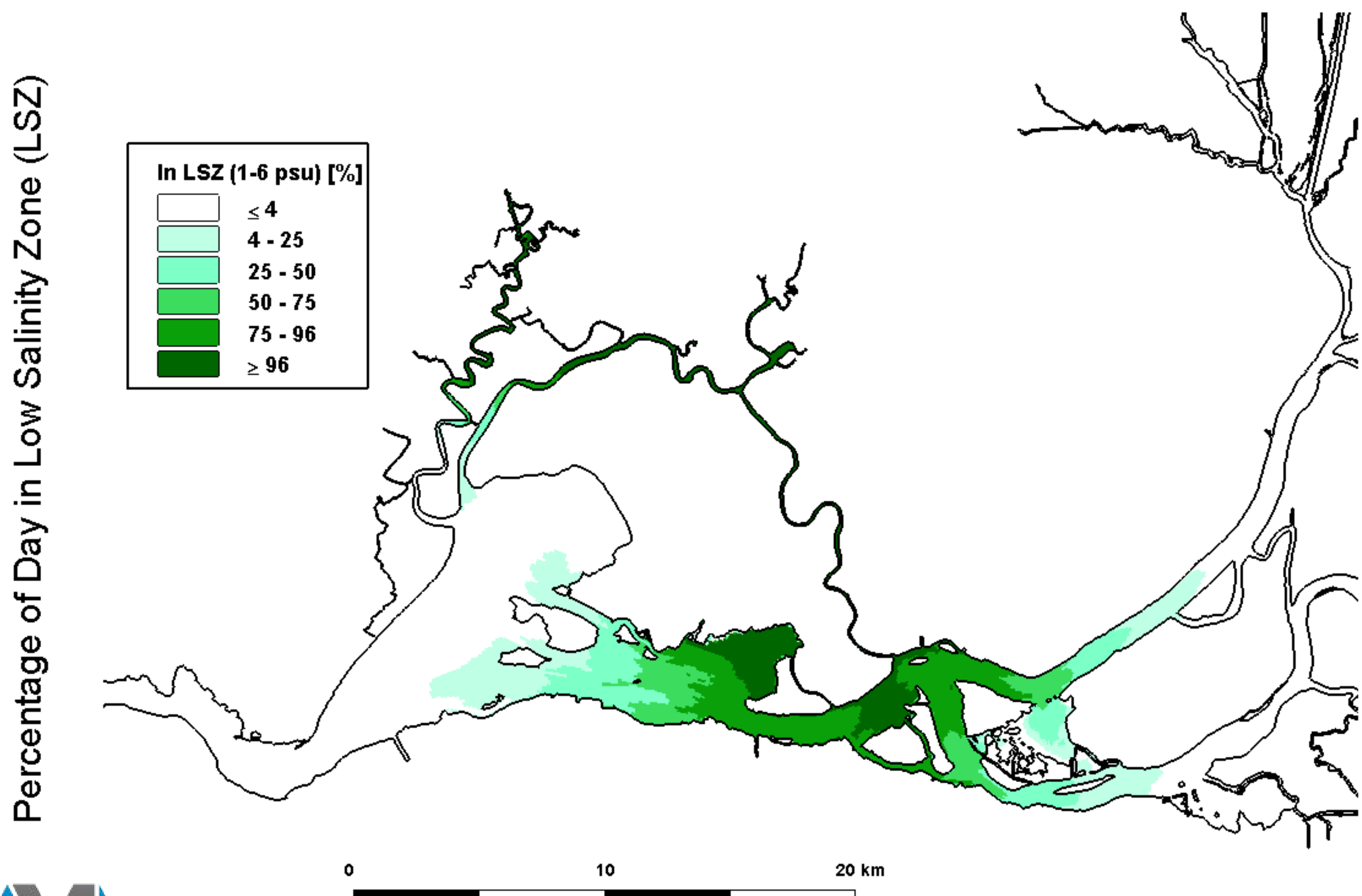
X2 ≈ 80


Daily-average Depth-averaged Salinity
Salinity [psu]
≤ 1
1 - 2
2 - 3
3 - 4
4 - 5
5 - 6
≥ 6
0
10
20 km

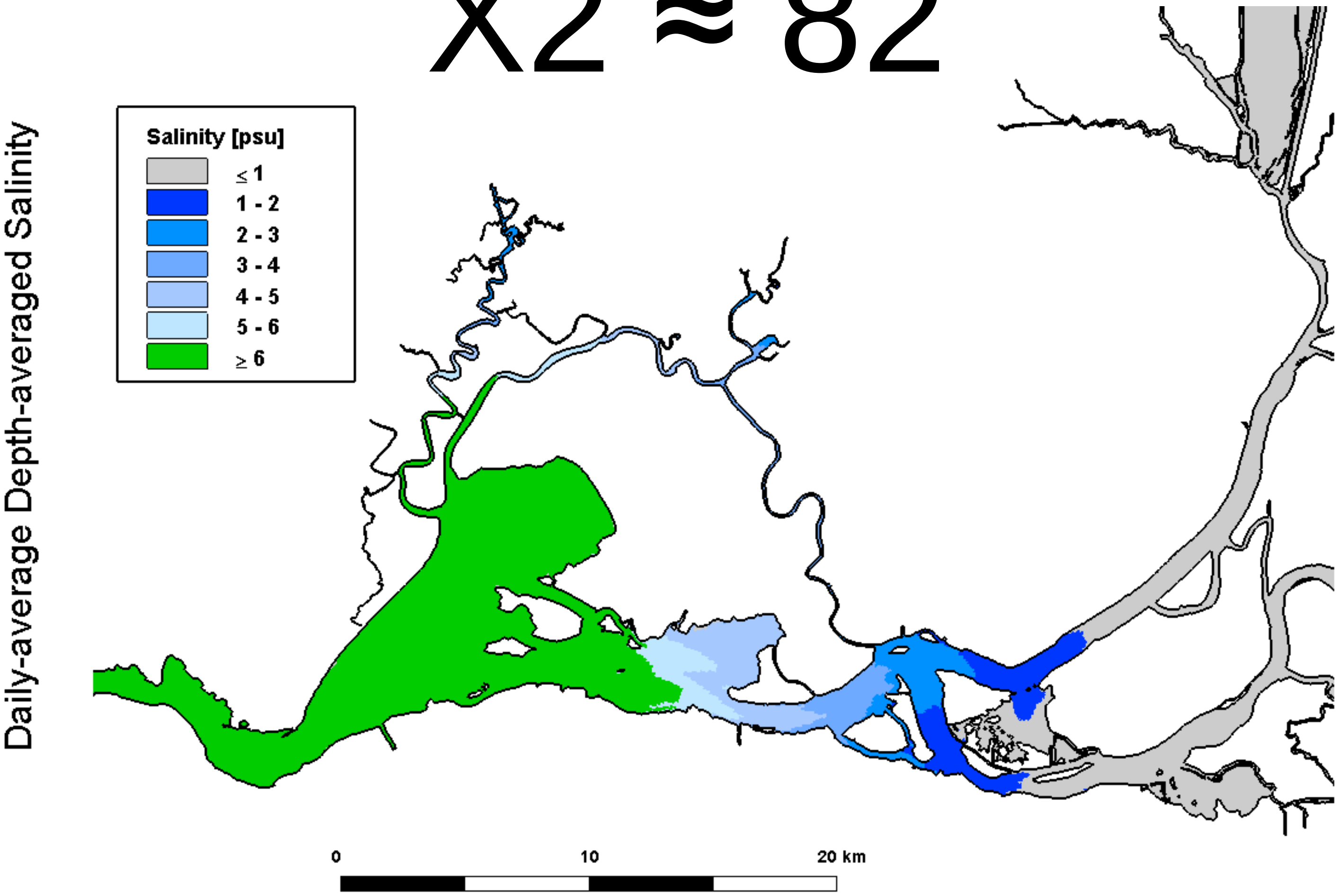

Percentage of Day in Low Salinity Zone (LSZ)
In LSZ (1-6 psu) [%]
≤ 4
4 - 25
25 - 50
50 - 75
75 - 96
≥ 96
0
10
20 km

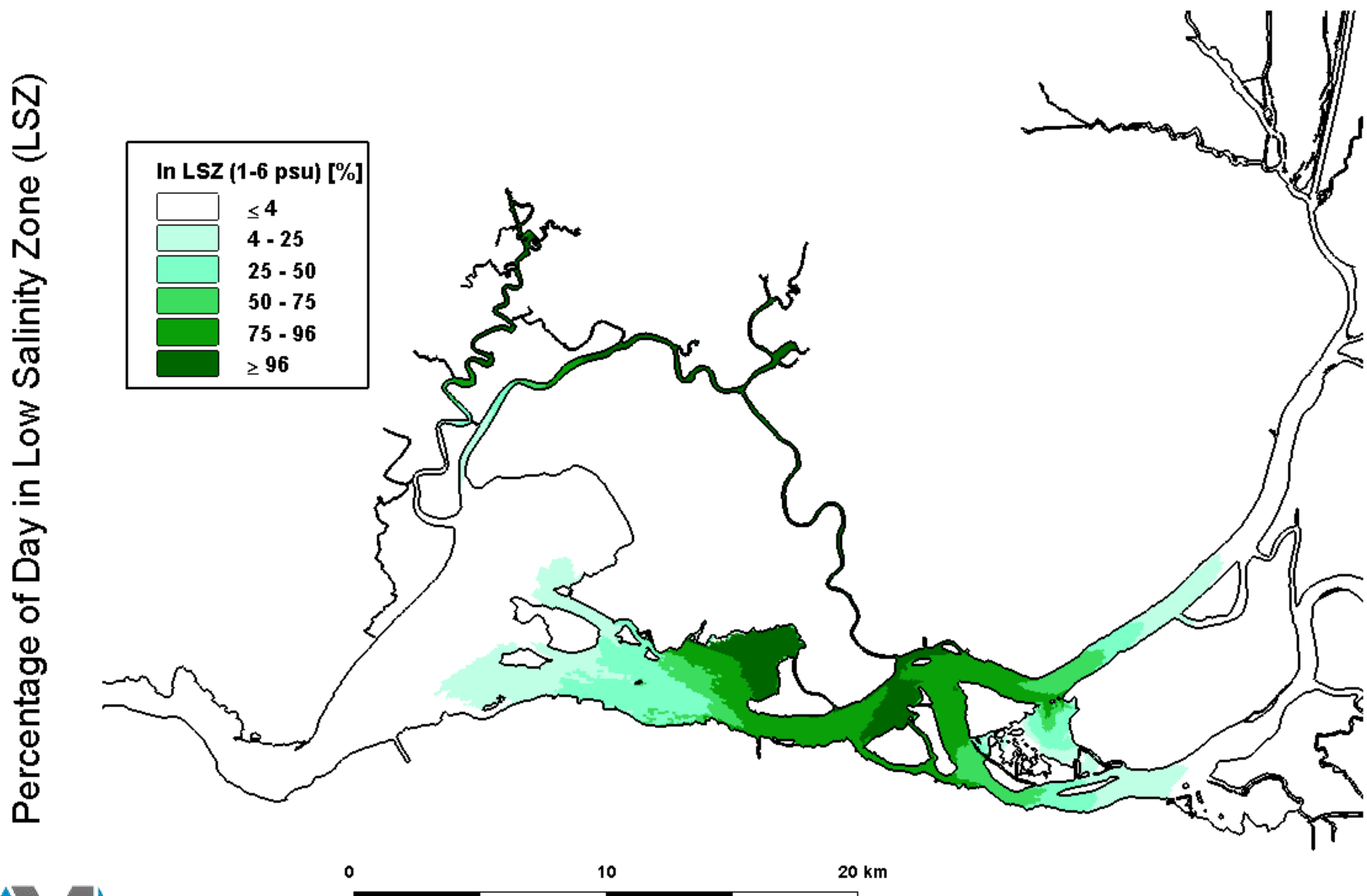
X2 ≈ 81


Daily-average Depth-averaged Salinity
Salinity [psu]
≤ 1
1 - 2
2 - 3
3 - 4
4 - 5
5 - 6
≥ 6
0
10
20 km

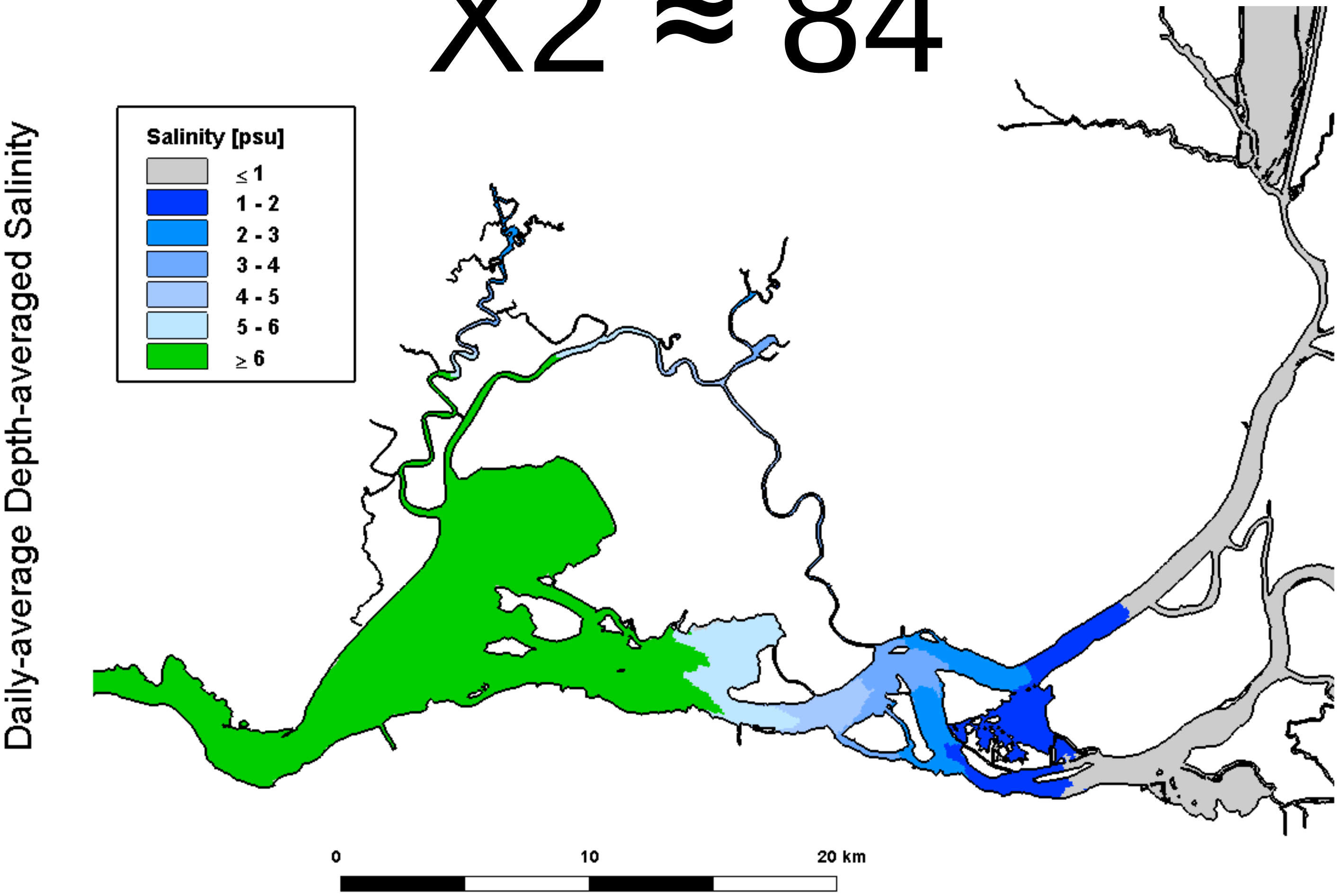

Percentage of Day in Low Salinity Zone (LSZ)
In LSZ (1-6 psu) [%]
≤ 4
4 - 25
25 - 50
50 - 75
75 - 96
≥ 96
0
10
20 km

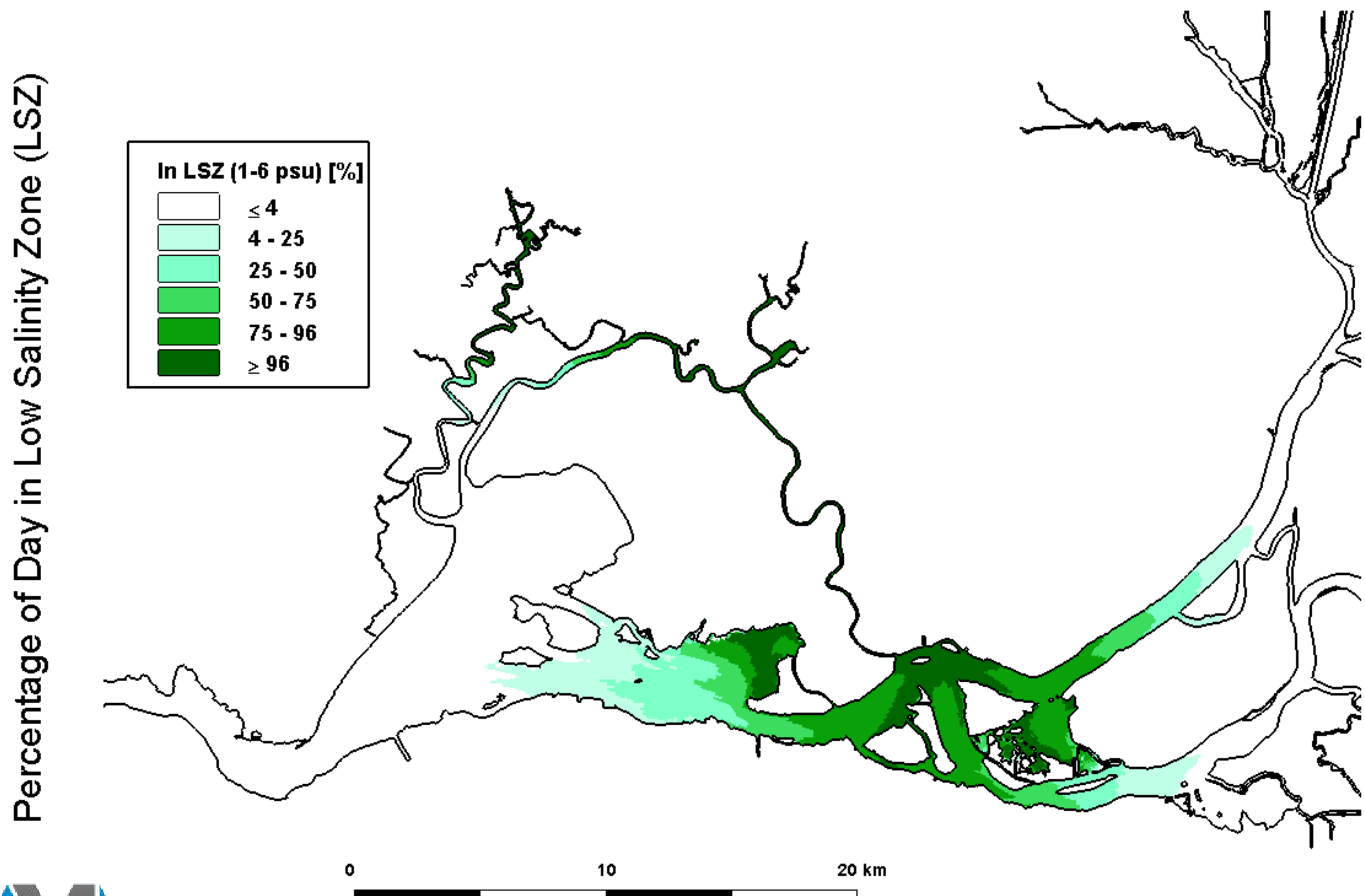
X2 ≈ 82


Daily-average Depth-averaged Salinity
Salinity [psu]
≤ 1
1 - 2
2 - 3
3 - 4
4 - 5
5 - 6
≥ 6
0
10
20 km

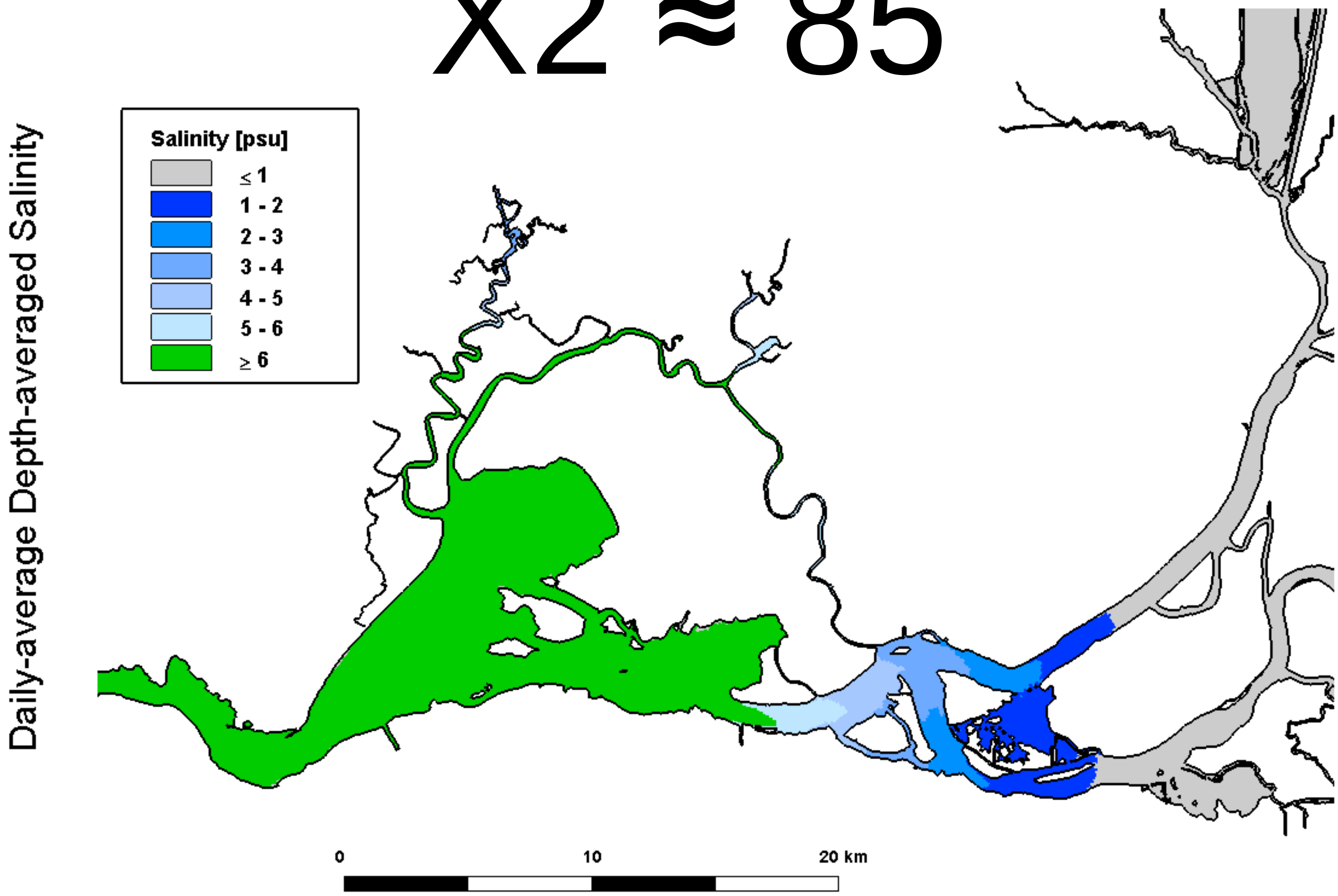

Percentage of Day in Low Salinity Zone (LSZ)
In LSZ (1-6 psu) [%]
≤ 4
4 - 25
25 - 50
50 - 75
75 - 96
≥ 96
0
10
20 km

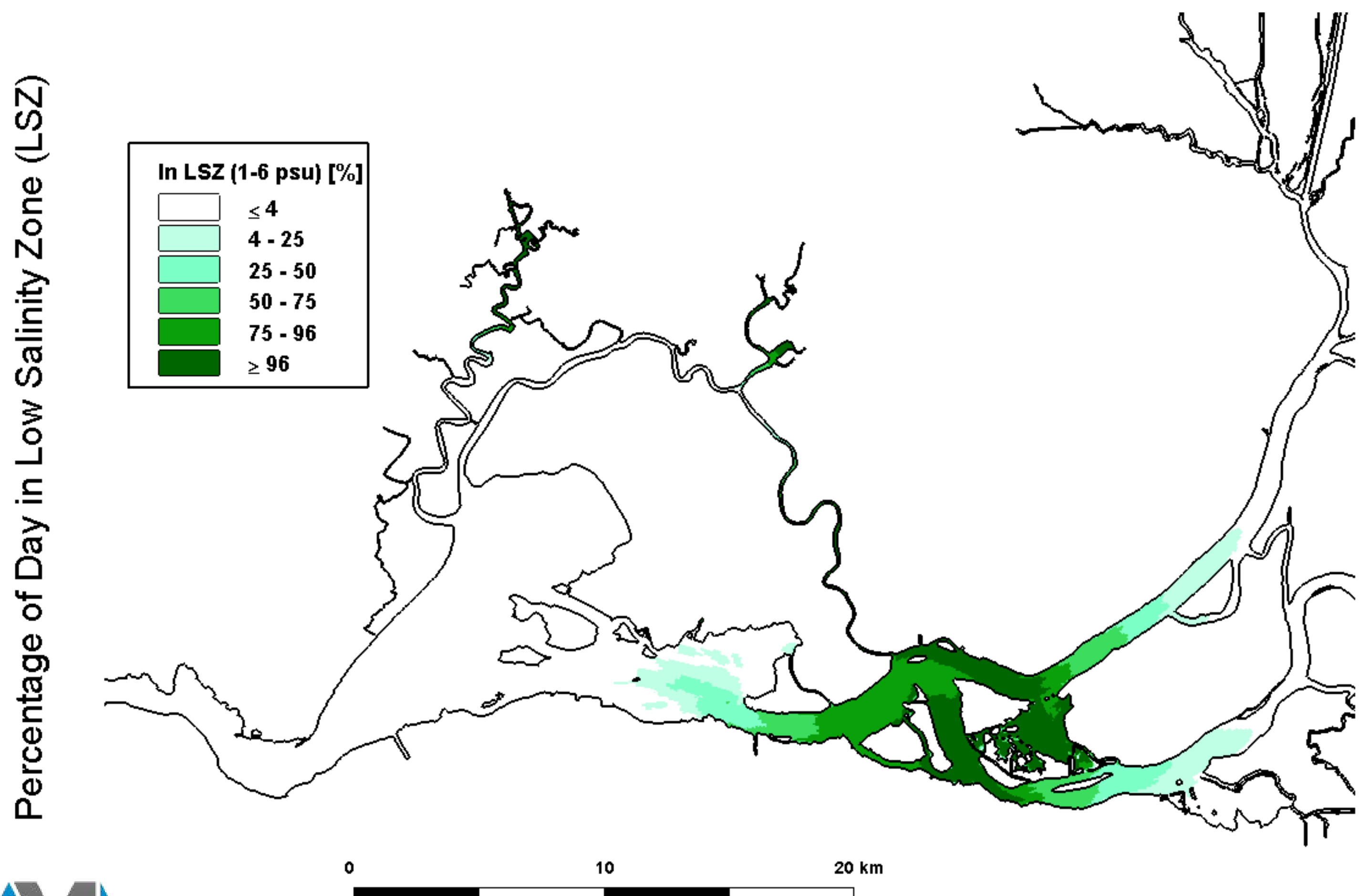
X2 ≈ 84


Daily-average Depth-averaged Salinity
Salinity [psu]
≤ 1
1 - 2
2 - 3
3 - 4
4 - 5
5 - 6
≥ 6
0
10
20 km

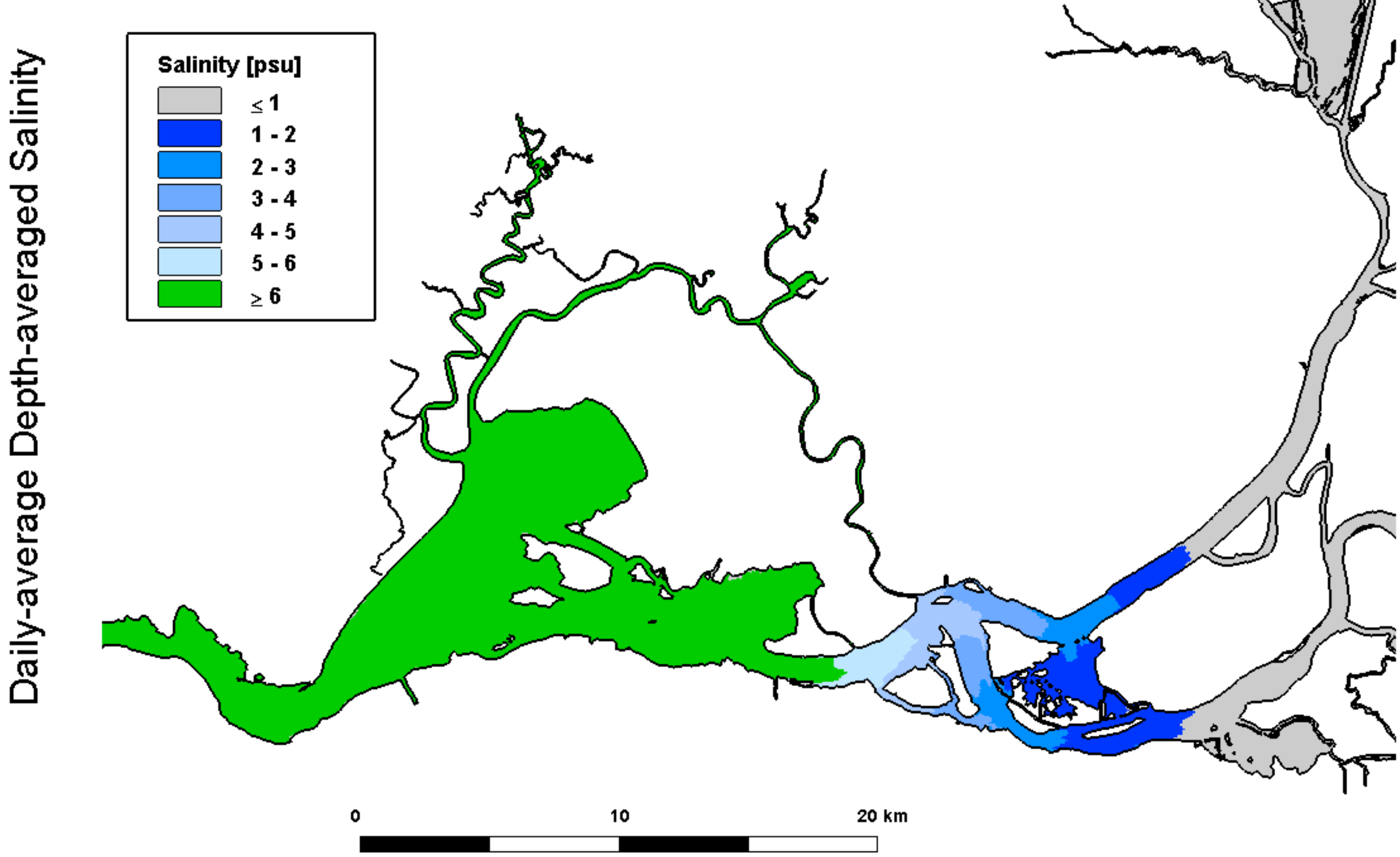

Percentage of Day in Low Salinity Zone (LSZ)
In LSZ (1-6 psu) [%]
≤ 4
4 - 25
25 - 50
50 - 75
75 - 96
≥ 96
0
10
20 km

X2 ≈ 85

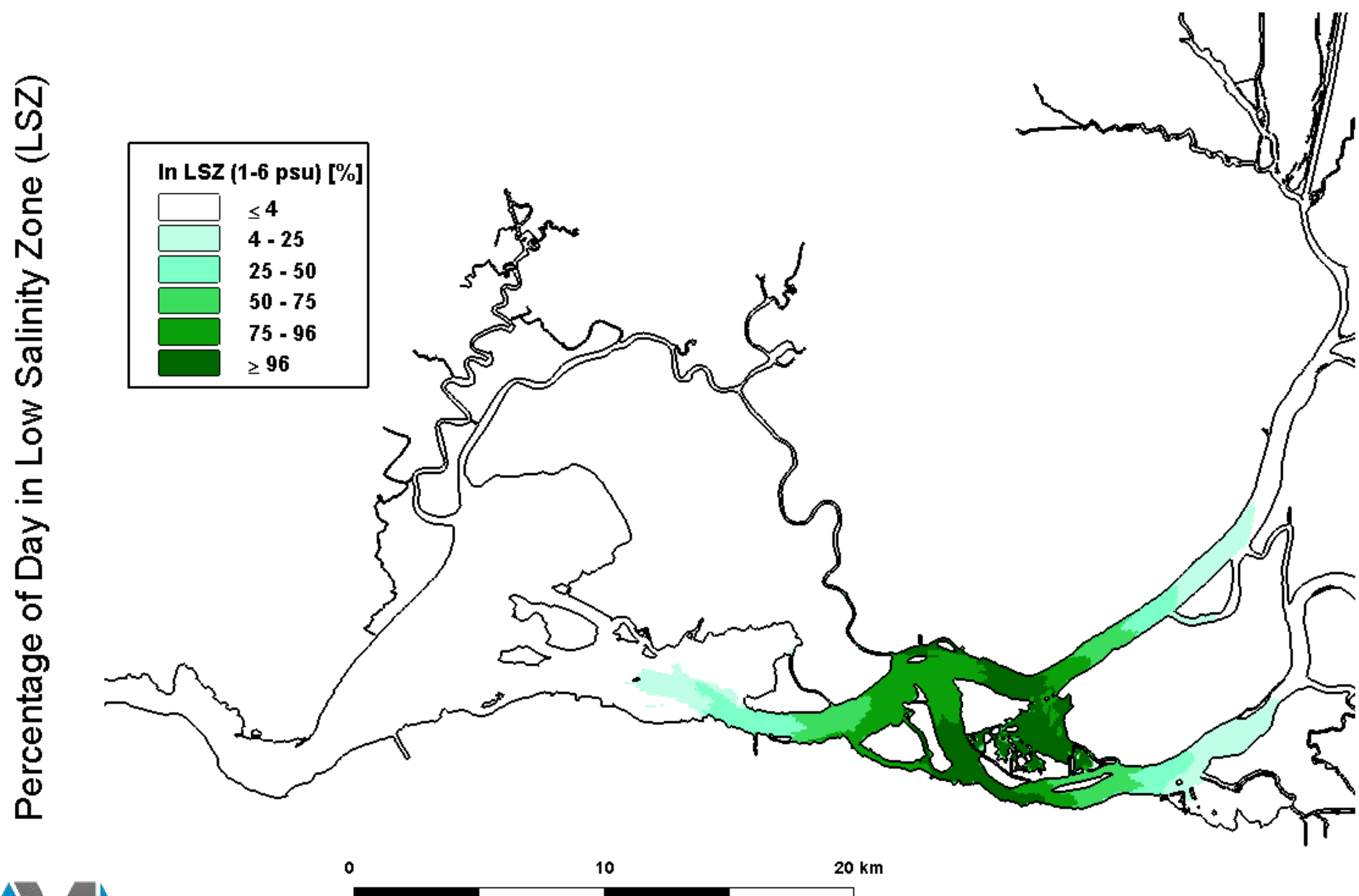

Daily-average Depth-averaged Salinity
Salinity [psu]
≤ 1
1 - 2
2 - 3
3 - 4
4 - 5
5 - 6
≥ 6
0
10
20 km


Percentage of Day in Low Salinity Zone (LSZ)
In LSZ (1-6 psu) [%]
≤ 4
4 - 25
25 - 50
50 - 75
75 - 96
≥ 96
0
10
20 km

X2 ≈ 86

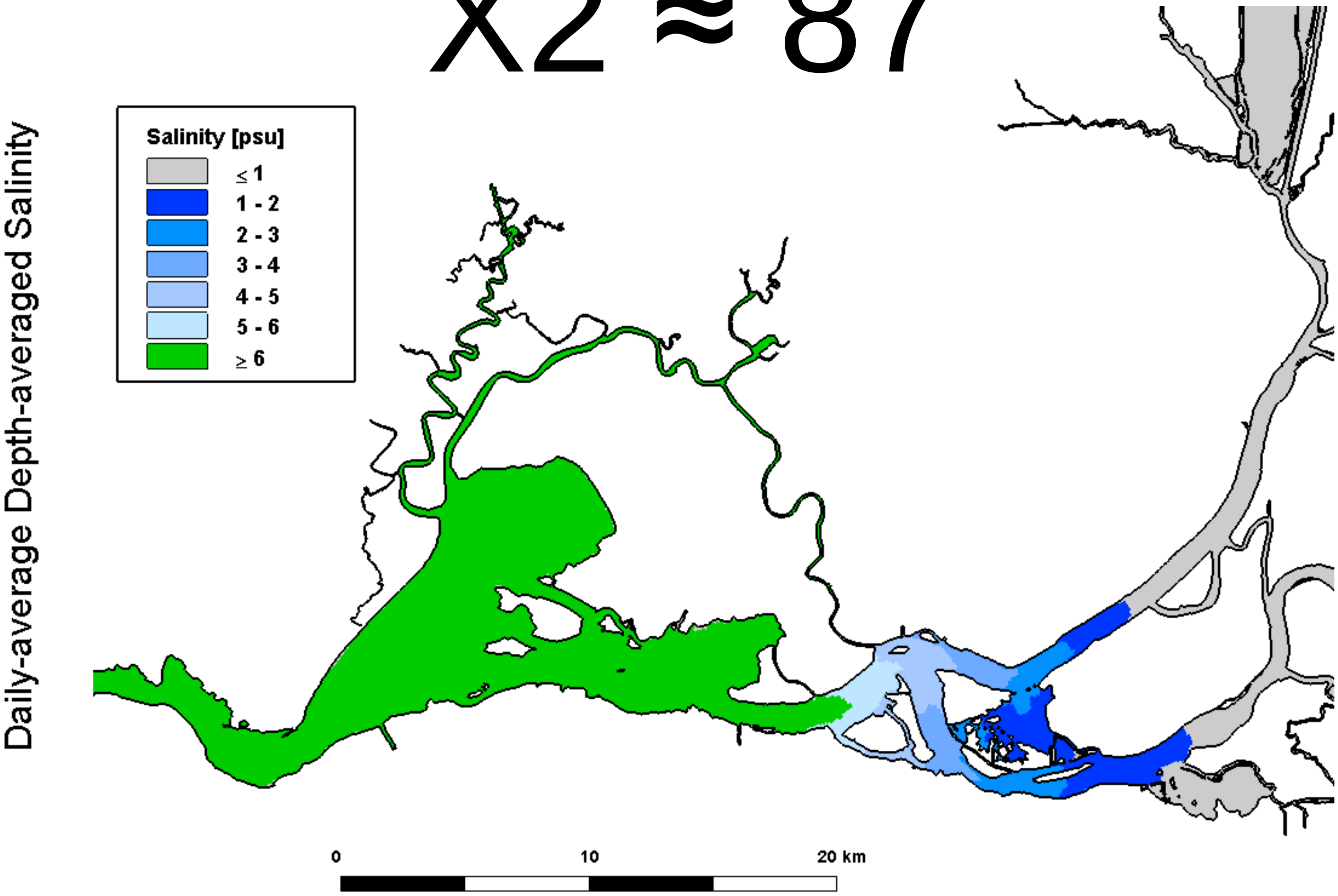


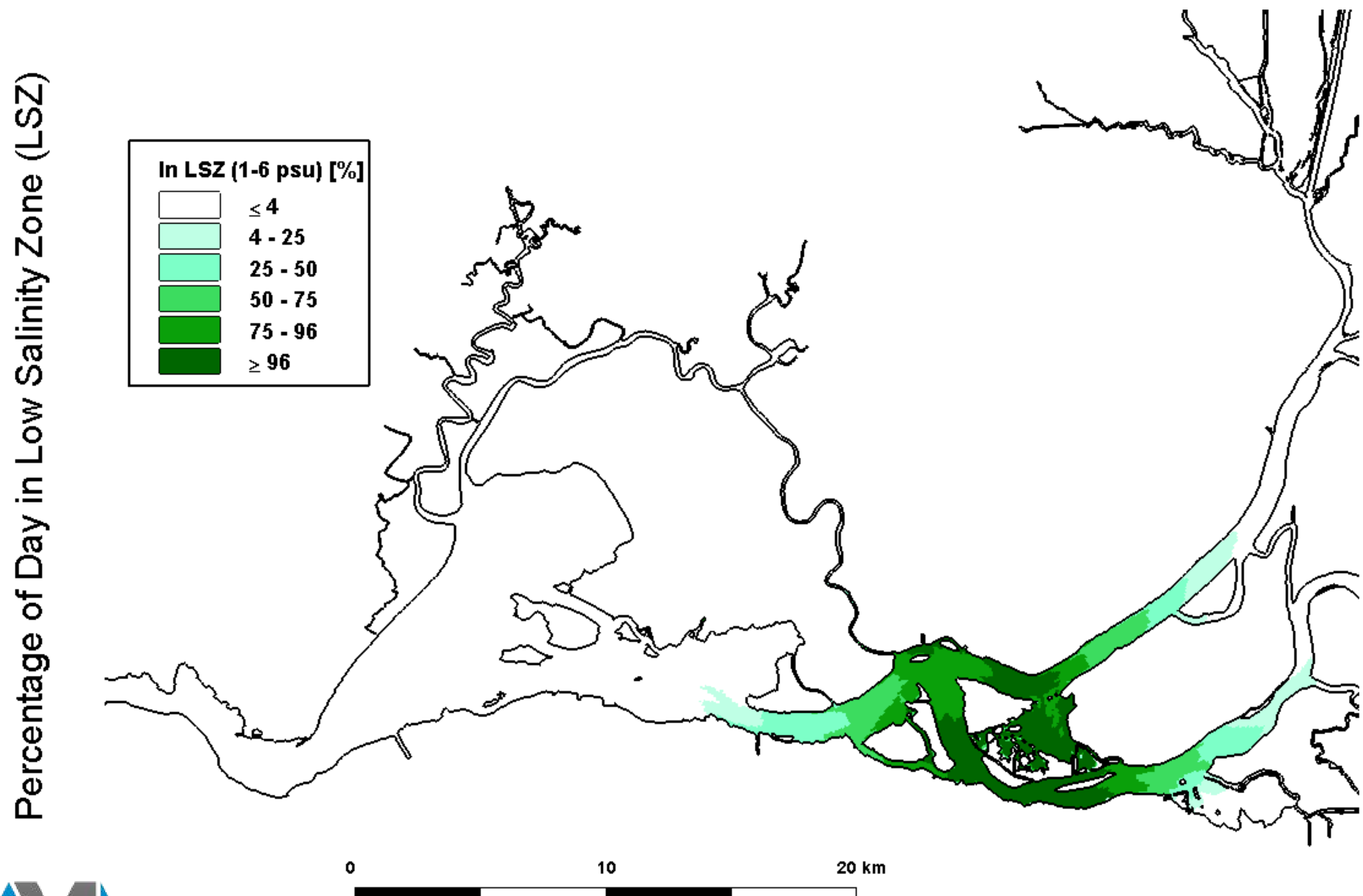
Daily-average Depth-averaged Salinity
Salinity [psu]
≤ 1
1 - 2
2 - 3
3 - 4
4 - 5
5 - 6
≥ 6
0
10
20 km



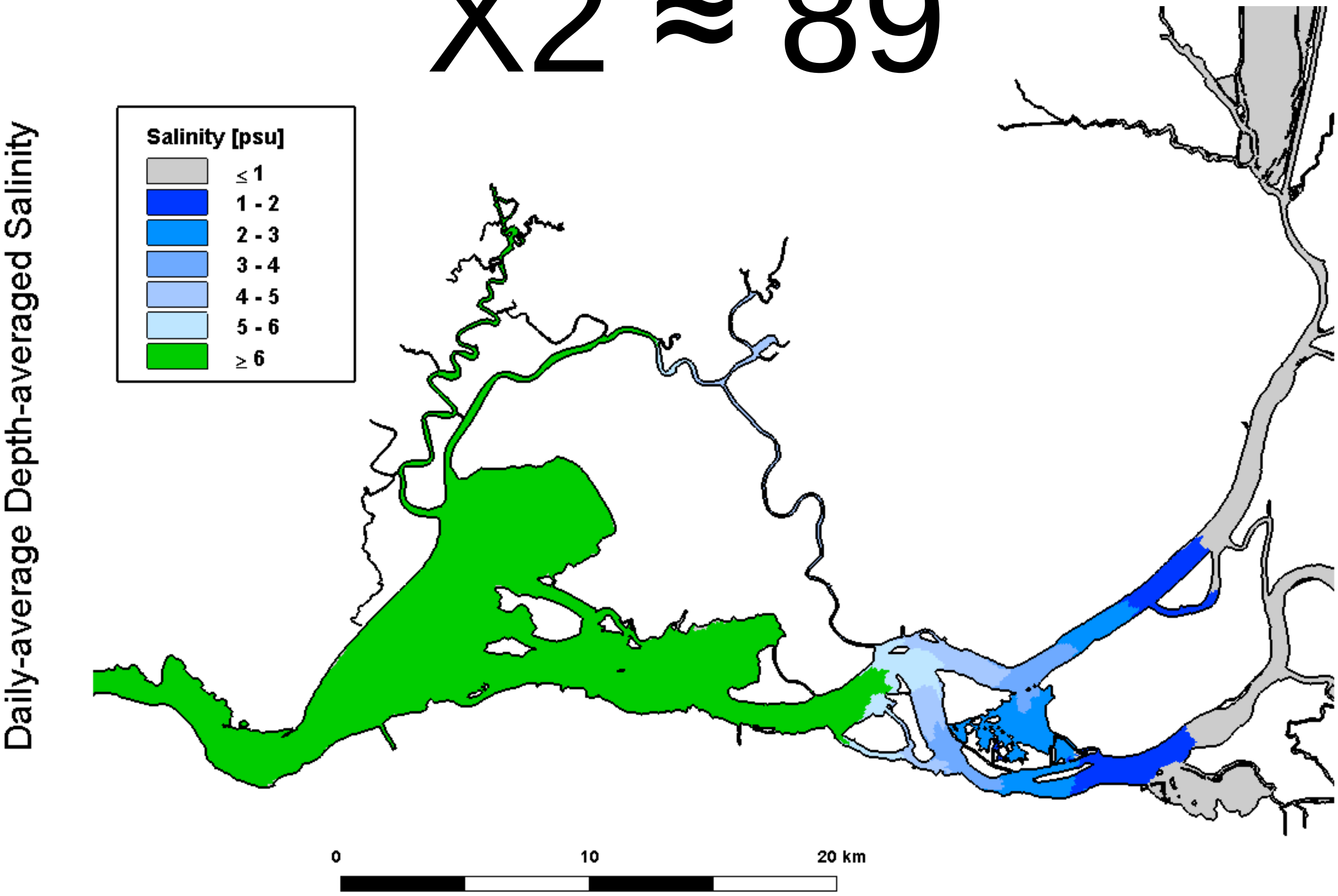
Percentage of Day in Low Salinity Zone (LSZ)
In LSZ (1-6 psu) [%]
≤ 4
4 - 25
25 - 50
50 - 75
75 - 96
≥ 96
0
10
20 km

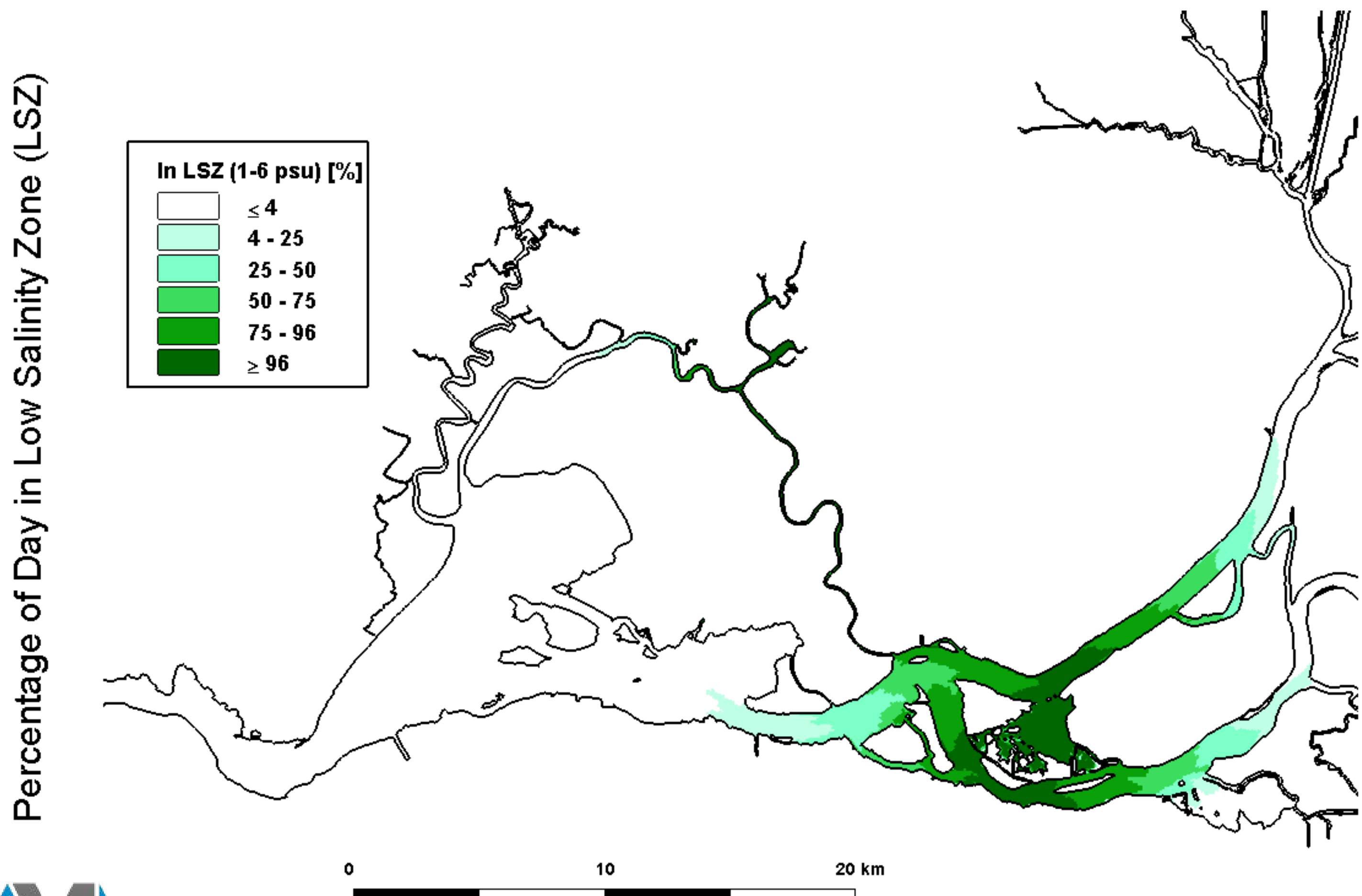
X2 ≈ 87


Daily-average Depth-averaged Salinity
Salinity [psu]
≤ 1
1 - 2
2 - 3
3 - 4
4 - 5
5 - 6
≥ 6
0
10
20 km

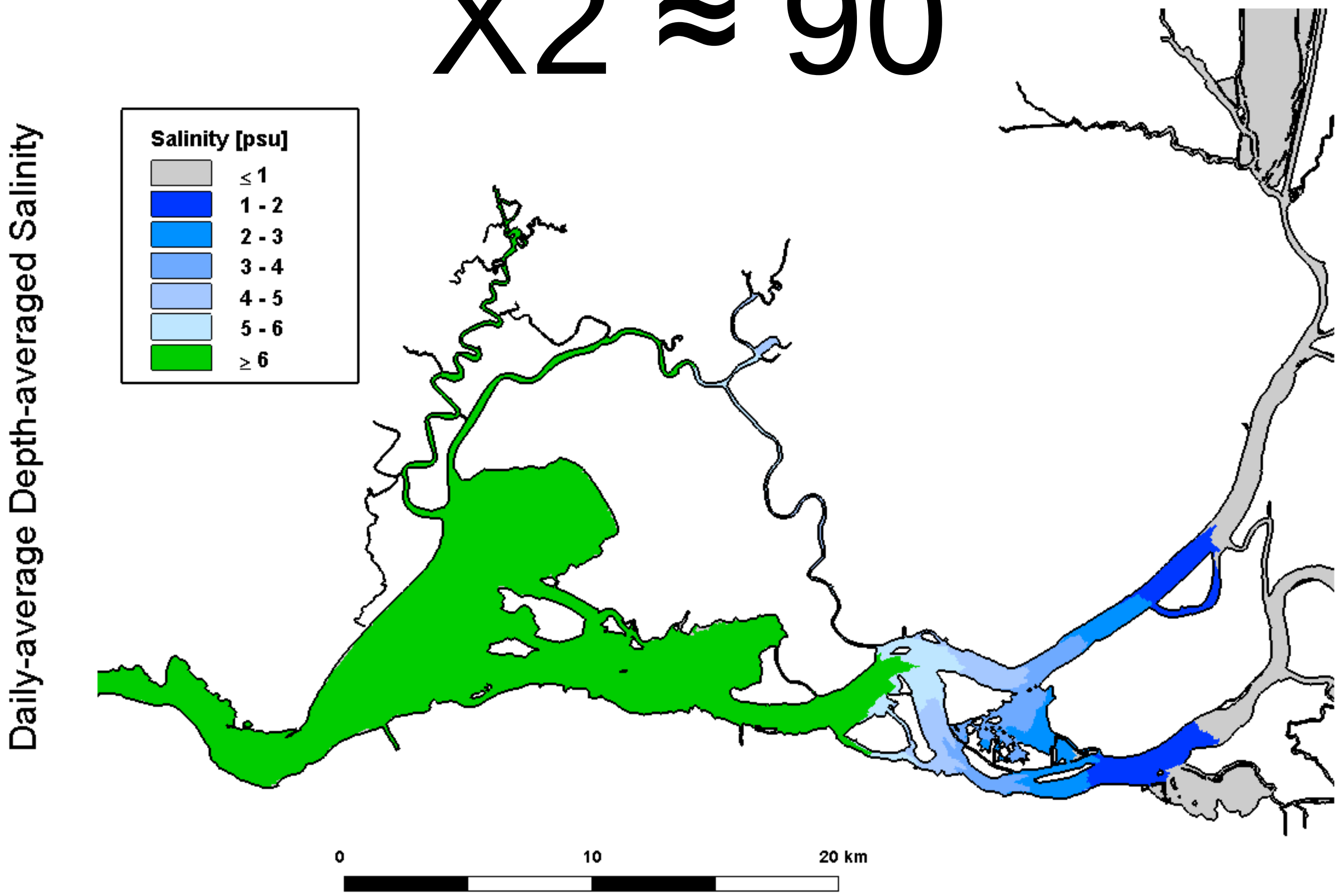

Percentage of Day in Low Salinity Zone (LSZ)
In LSZ (1-6 psu) [%]
≤ 4
4 - 25
25 - 50
50 - 75
75 - 96
≥ 96
0
10
20 km

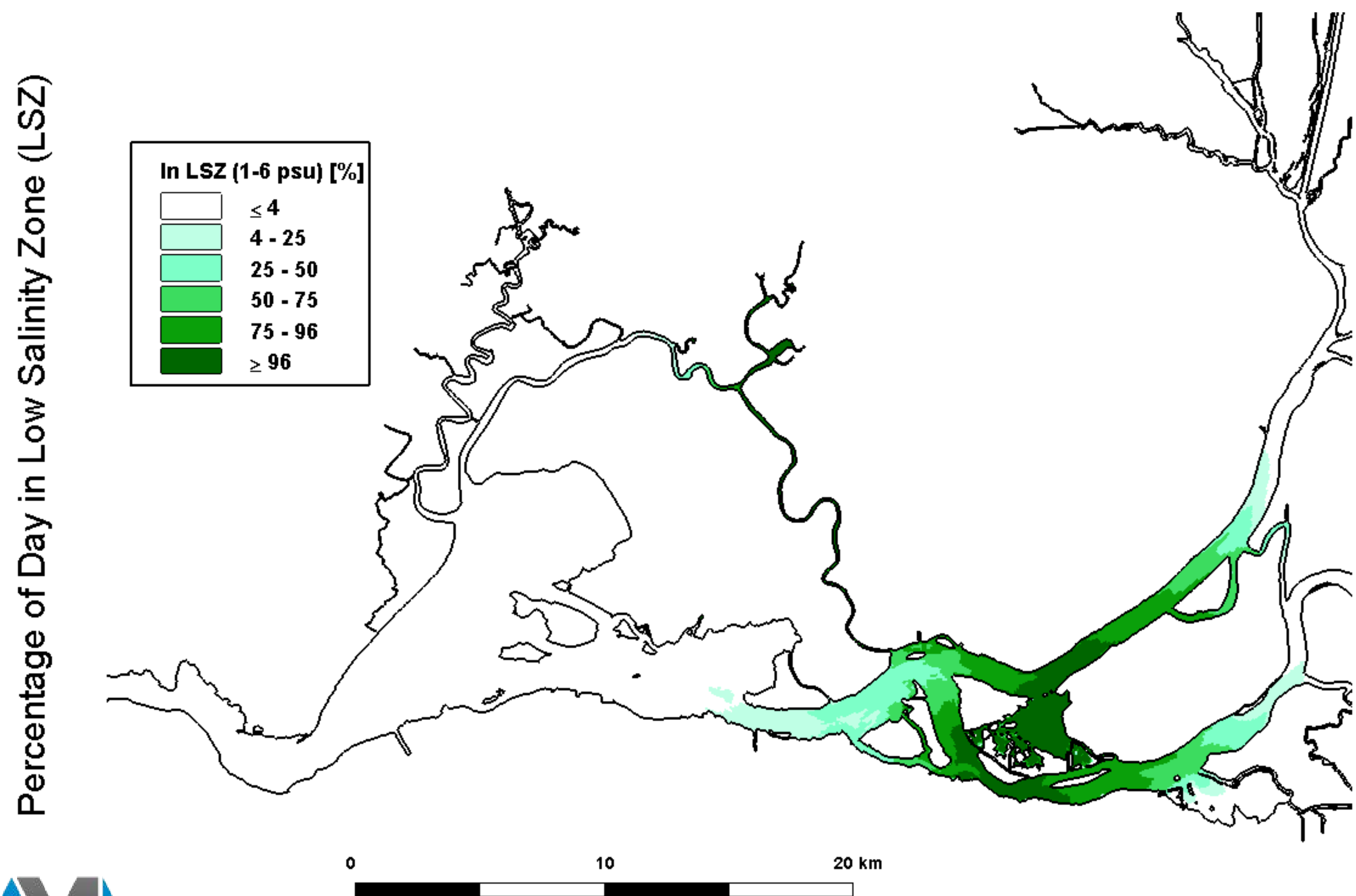
X2 ≈ 89


Daily-average Depth-averaged Salinity
Salinity [psu]
≤ 1
1 - 2
2 - 3
3 - 4
4 - 5
5 - 6
≥ 6
0
10
20 km

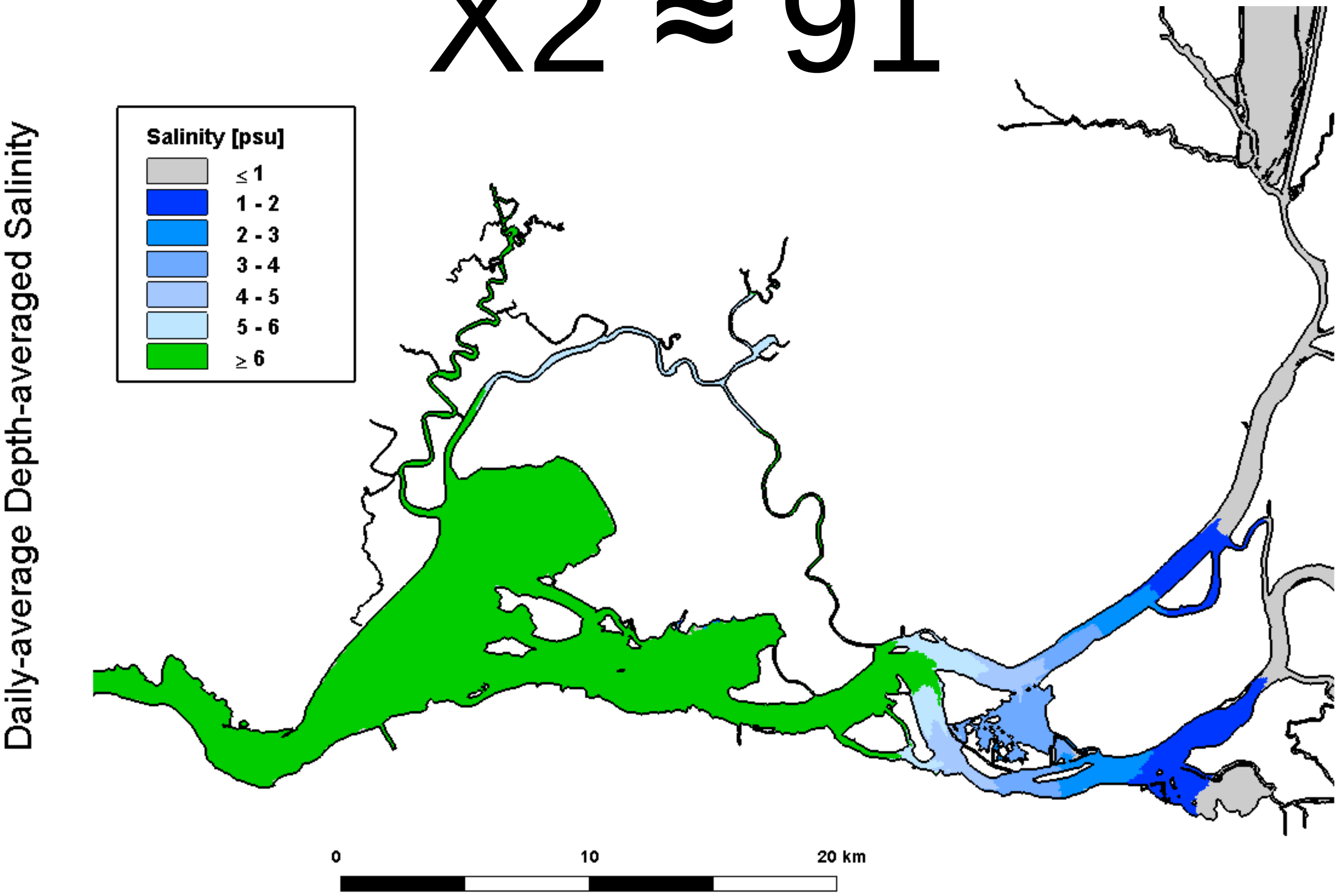

Percentage of Day in Low Salinity Zone (LSZ)
In LSZ (1-6 psu) [%]
≤ 4
4 - 25
25 - 50
50 - 75
75 - 96
≥ 96
0
10
20 km

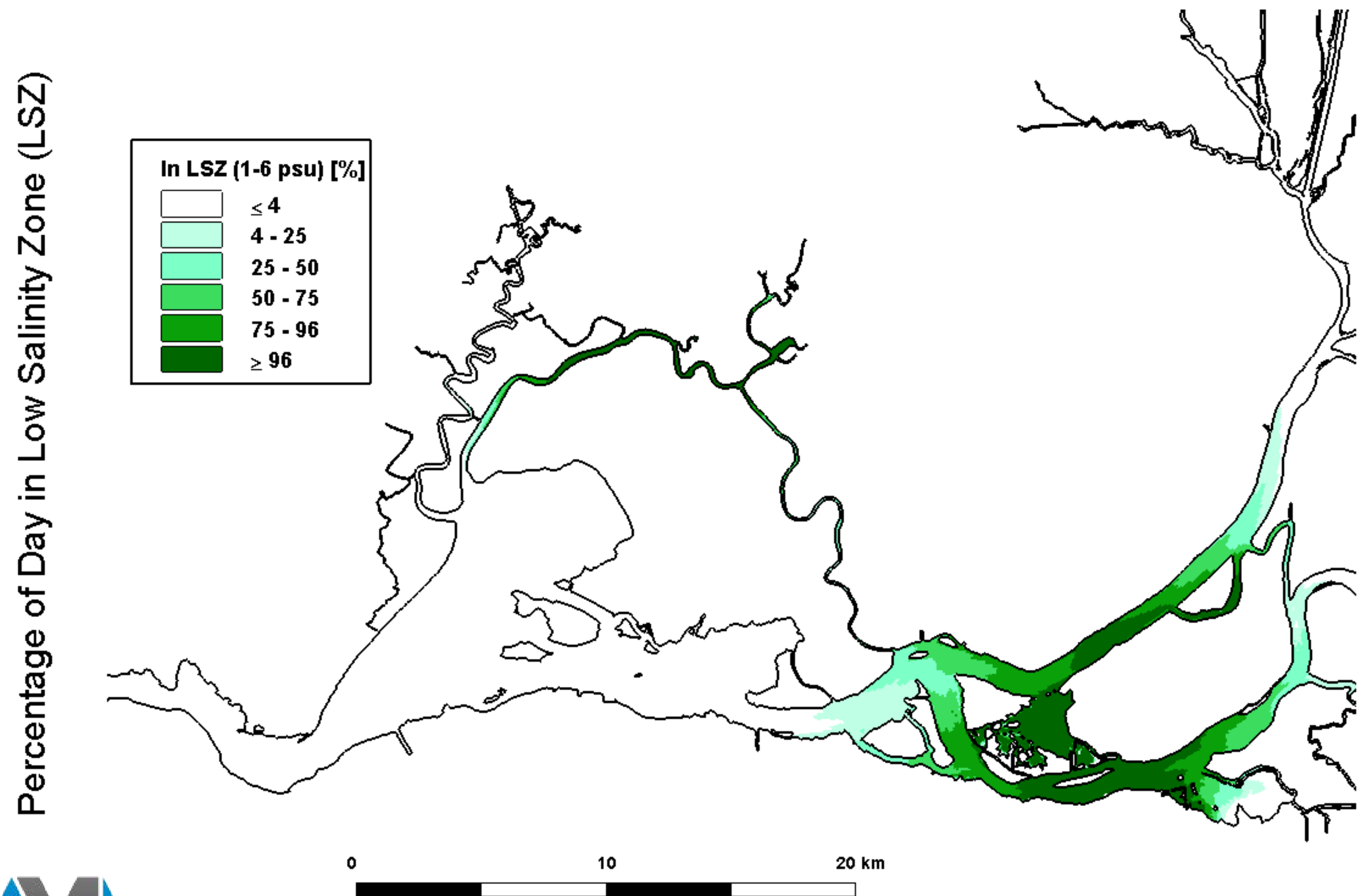
X2 ≈ 90


Daily-average Depth-averaged Salinity
Salinity [psu]
≤ 1
1 - 2
2 - 3
3 - 4
4 - 5
5 - 6
≥ 6
0
10
20 km

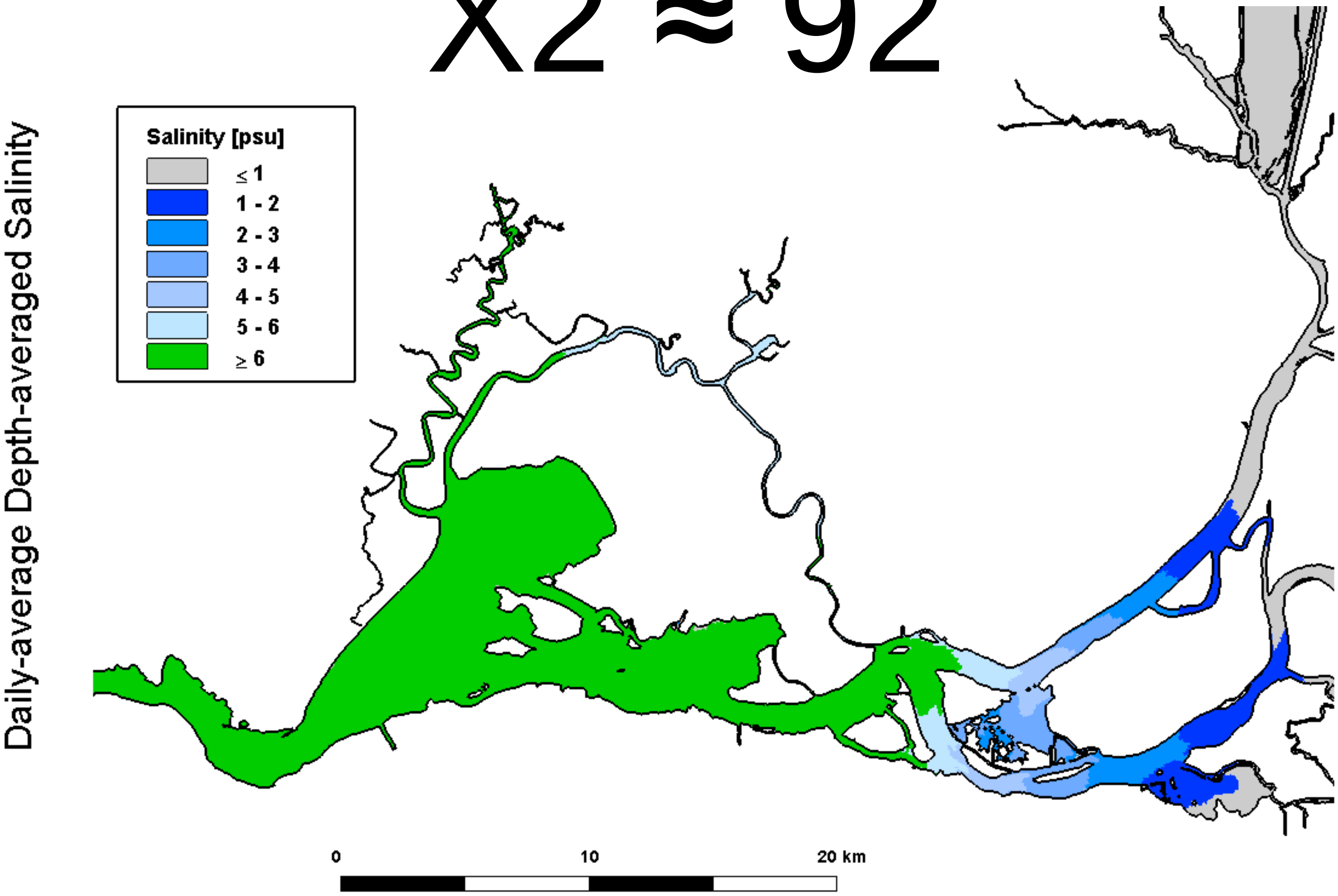

Percentage of Day in Low Salinity Zone (LSZ)
In LSZ (1-6 psu) [%]
≤ 4
4 - 25
25 - 50
50 - 75
75 - 96
≥ 96
0
10
20 km

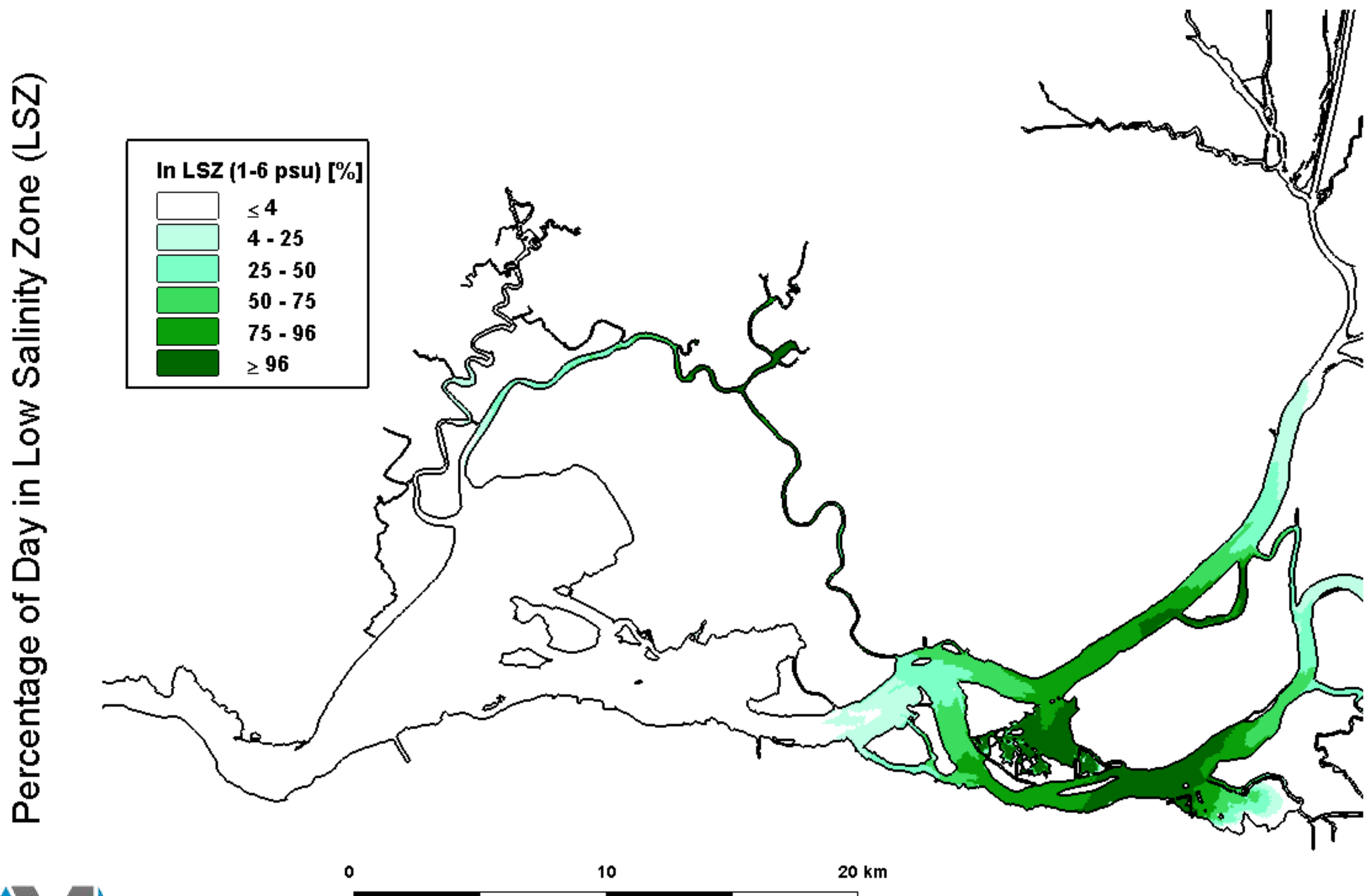
X2 ≈ 91


Daily-average Depth-averaged Salinity
Salinity [psu]
≤ 1
1 - 2
2 - 3
3 - 4
4 - 5
5 - 6
≥ 6
0
10
20 km

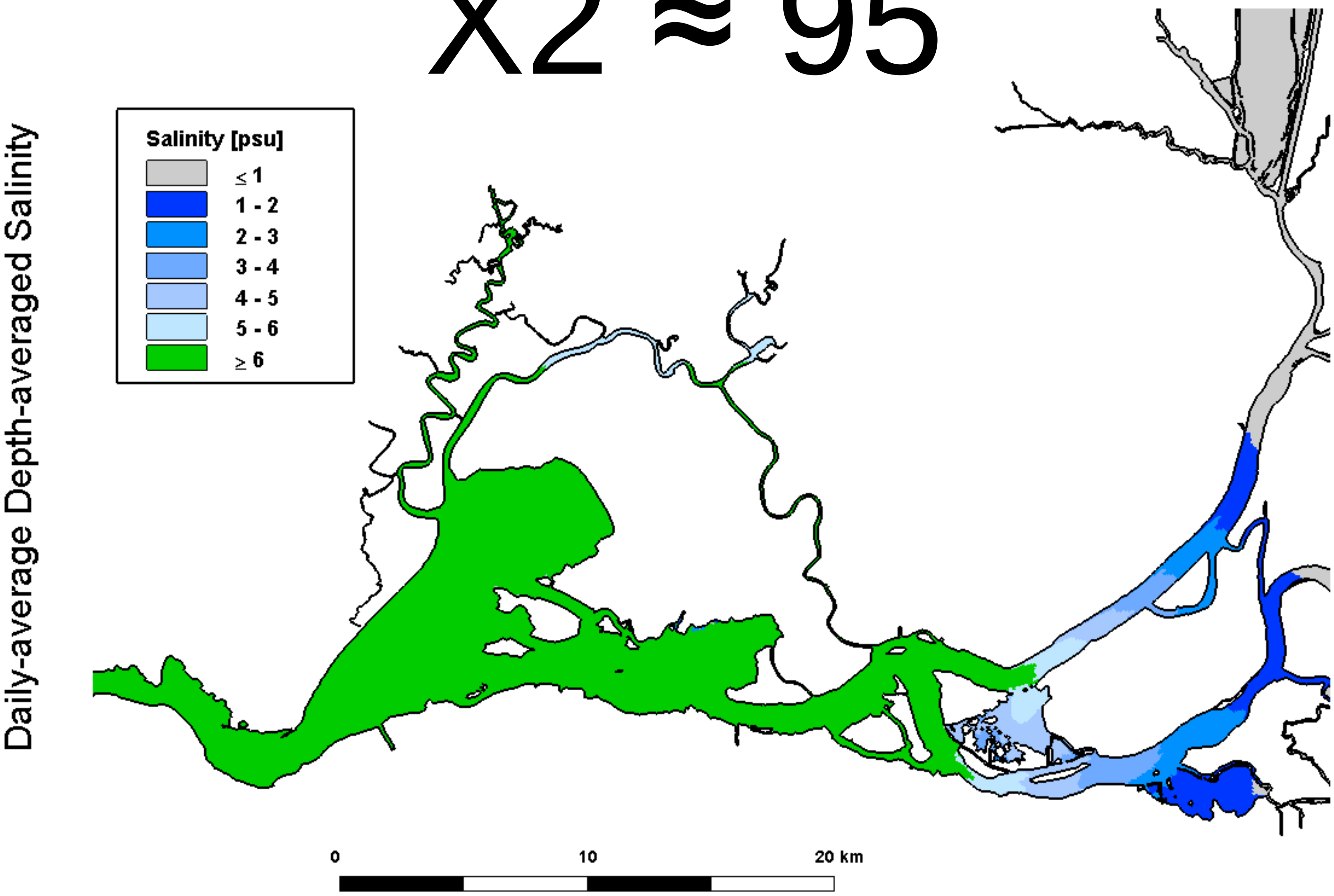

Percentage of Day in Low Salinity Zone (LSZ)
In LSZ (1-6 psu) [%]
≤ 4
4 - 25
25 - 50
50 - 75
75 - 96
≥ 96
0
10
20 km

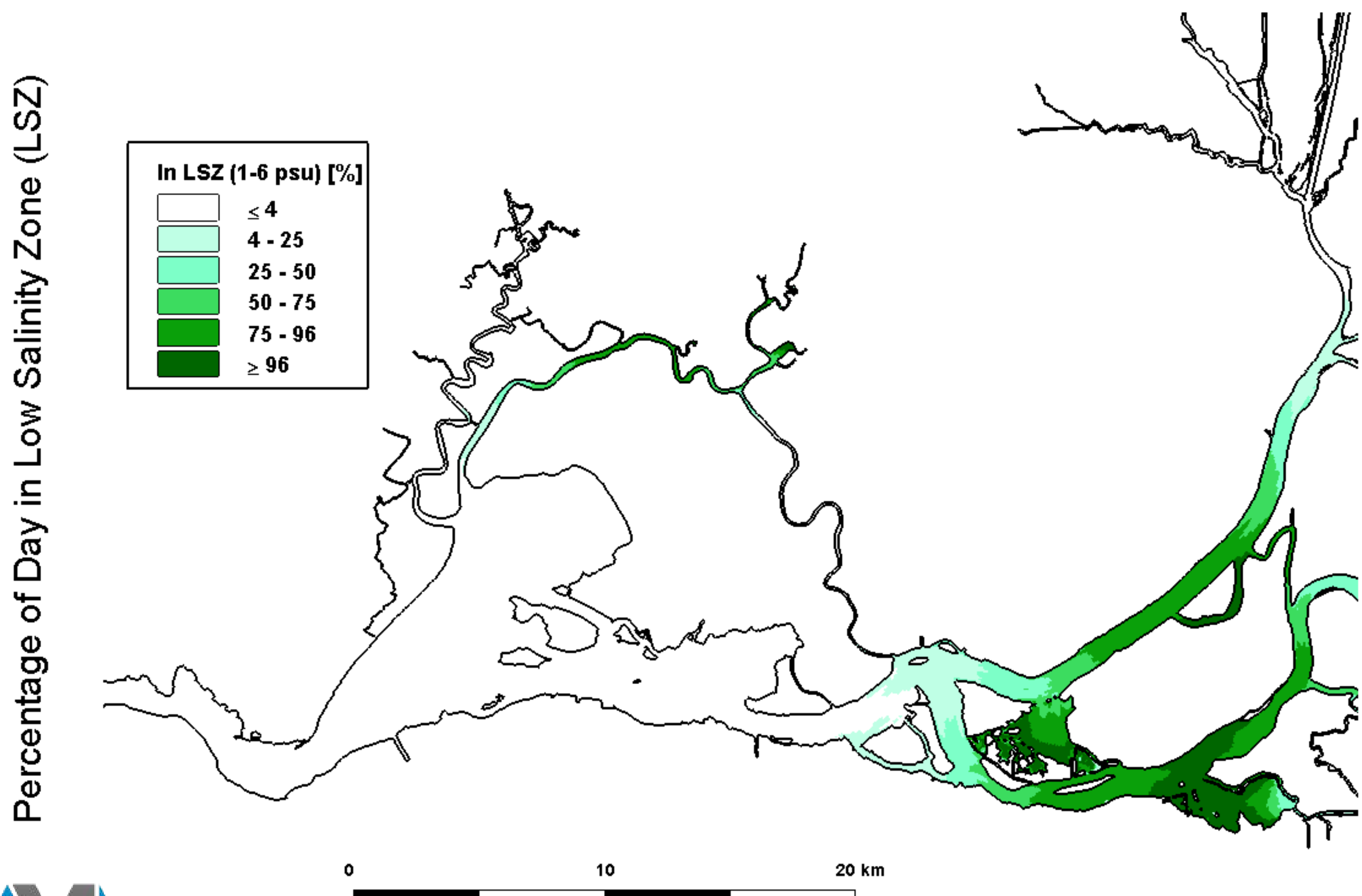
X2 ≈ 92


Daily-average Depth-averaged Salinity
Salinity [psu]
≤ 1
1 - 2
2 - 3
3 - 4
4 - 5
5 - 6
≥ 6
0
10
20 km


Percentage of Day in Low Salinity Zone (LSZ)
In LSZ (1-6 psu) [%]
≤ 4
4 - 25
25 - 50
50 - 75
75 - 96
≥ 96
0
10
20 km

X2 ≈ 95


Daily-average Depth-averaged Salinity
Salinity [psu]
≤ 1
1 - 2
2 - 3
3 - 4
4 - 5
5 - 6
≥ 6
0
10
20 km

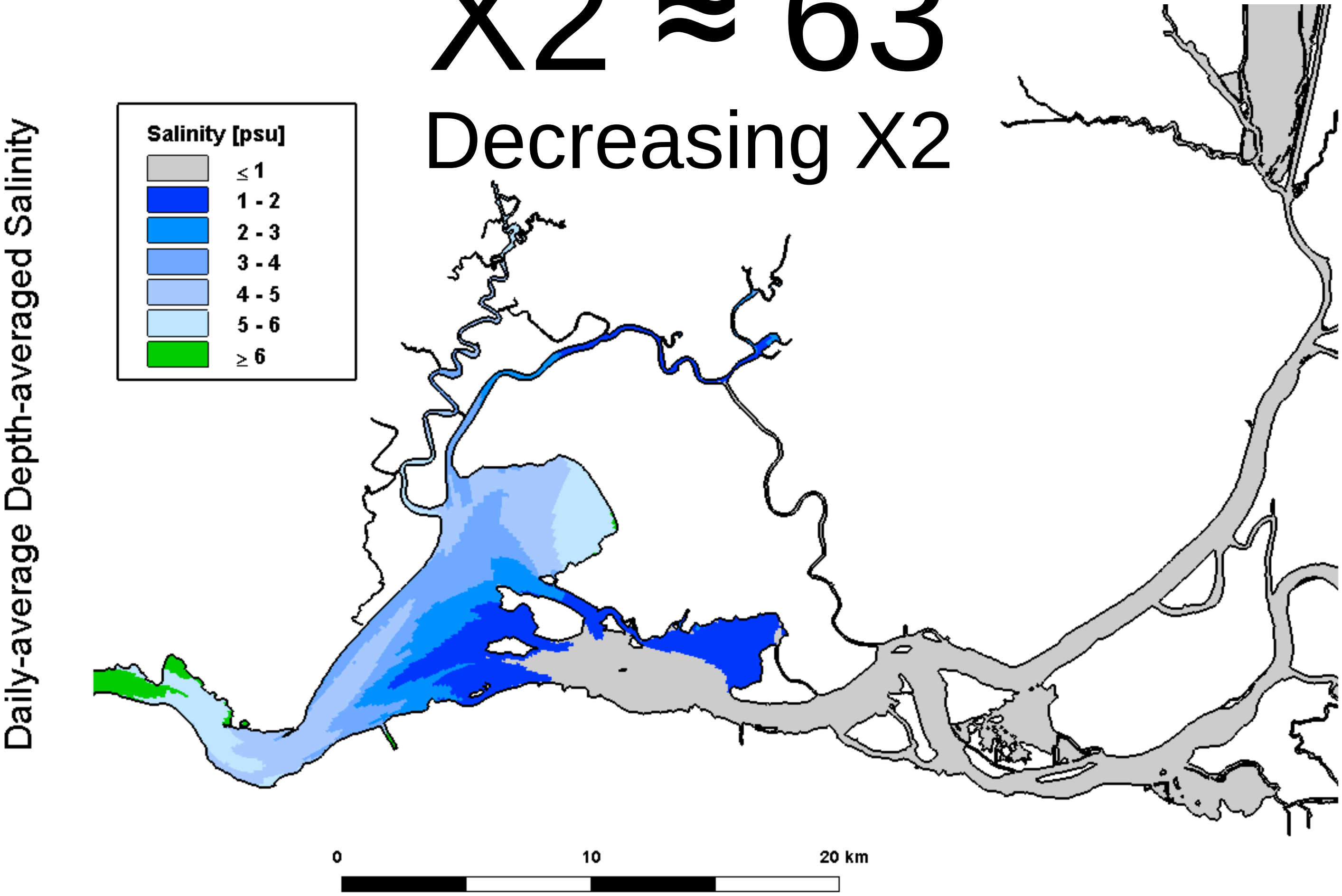

Percentage of Day in Low Salinity Zone (LSZ)
In LSZ (1-6 psu) [%]
≤ 4
4 - 25
25 - 50
50 - 75
75 - 96
≥ 96
0
10
20 km

Discussion

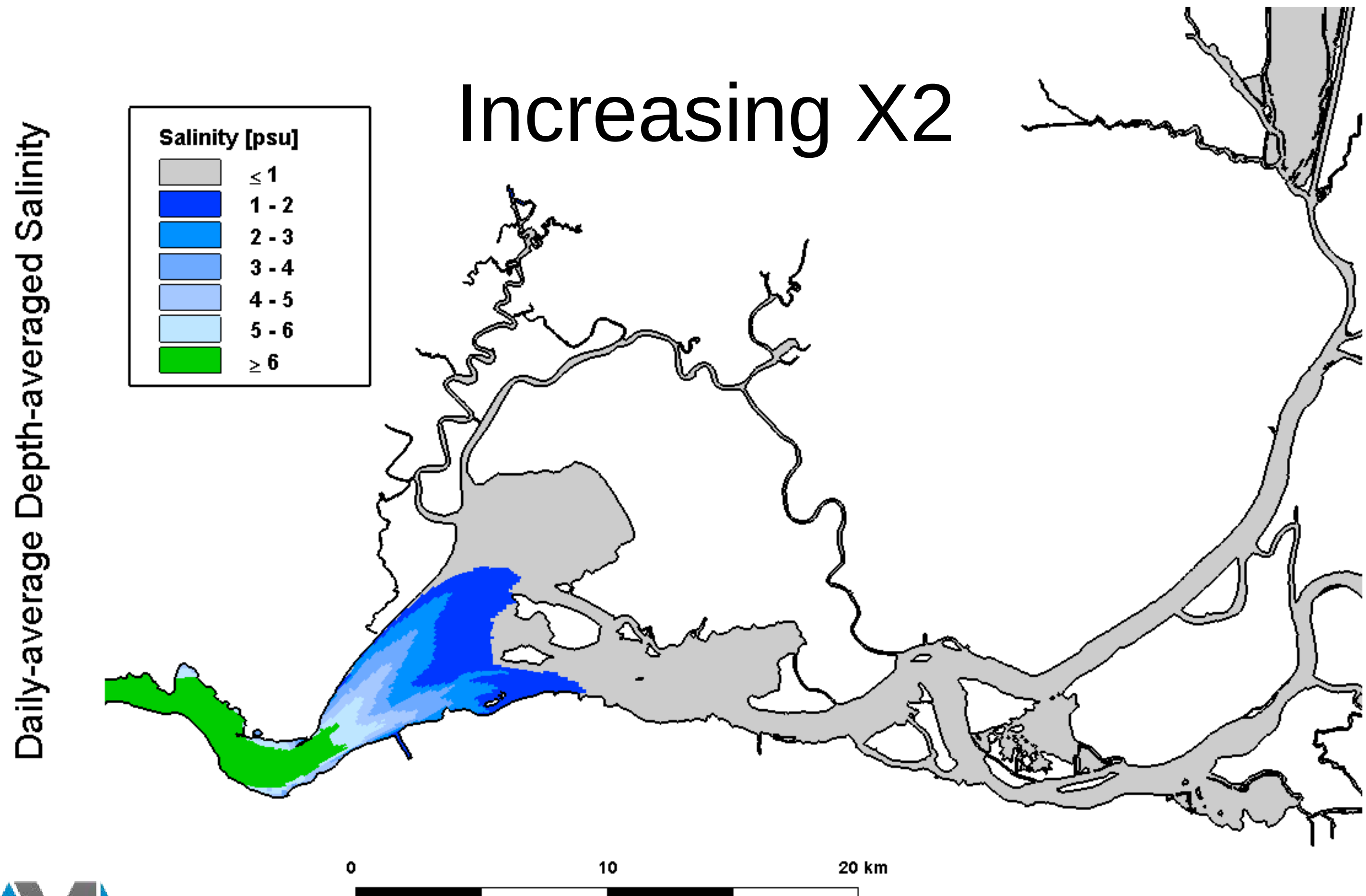
- The spatial distribution of the LSZ for a given X2 is influenced by the antecedent conditions.
- For example, from X2≈80 to X2≈81 (page 18-19) the LSZ shifts out of Grixzzly Bay with a relatively small increase in X2. However, these two figures show two days that are 41 days apart during which X2 varies between 75 and 81 km.
- Similarly, for X2≈63 (page 31), the distribution of the LSZ is strongly influenced by antecedent conditions and whether X2 is decreasing or increasing.

X2 ≈ 63

Decreasing X2



Increasing X2



Comments and Suggestions

- The “Low Salinity Zone Flip Book” is intended as a dynamic document.
- The goal of this document is to encourage discussion of ways of thinking about X2 and the LSZ both spatially and temporally.
- Comments and suggestions for additional analysis to be included in future revisions are welcome.
- Please address any comments to:

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